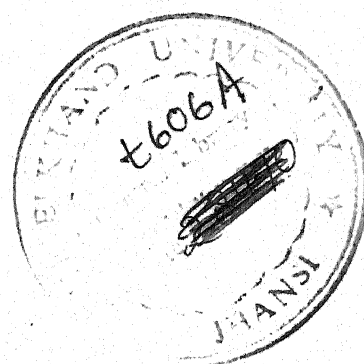


**Histomorphological Studies Of The  
Olfactory Organs Of Some Freshwater  
Indian Teleosts**

THESIS PRESENTED FOR THE DEGREE OF  
**DOCTOR OF PHILOSOPHY**

IN  
**ZOOLOGY**



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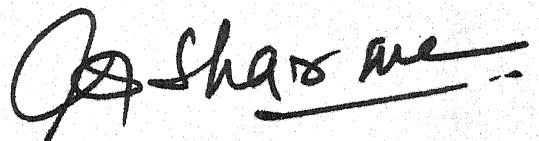
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C E R T I F I C A T E

I certify that, "Histomorphological studies of the olfactory organs of some freshwater Indian teleosts", is the original work of Mr. Om Prakash Yadav, Lecturer, Department of Zoology, Bipin Behari College, Jhansi and is suitable for the award of the degree of Doctor of Philosophy in Zoology of the Bundelkhand University, Jhansi. This work has been done by the candidate under my supervision.



(VIJAI INDRA SHARMA)

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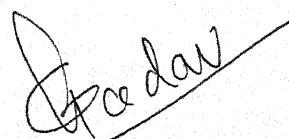
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( OM PRAKASH YADAV )

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INTRODUCTION AND HISTORICAL REVIEW

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## INTRODUCTION AND HISTORICAL REVIEW

Sensory receptors are the immediate detectors of environmental stimuli. These may be of chemical, physical and mechanical nature. Chemical receptors detect olfaction and taste, physical light and temperature and mechanical position and motion etc. Among the receptors of fish, one of the important sense is the olfaction, which maintains the contact of the organism with its external environment and supplies informations regarding the variation of behavioral responses in relation to the changing effects of biotic and abiotic factors. In fishes the sense of olfaction plays a major and sometimes decisive role in feeding, defence, spawning, schooling, orientation and migration, as they are restricted to the aqueous environment.

Historically, the existence of sense of smell in fish has long been controversial. Nagel (1894) denied the existence of true olfactory sense in aquatic animals, premissing that the organ of smell can only be stimulated by gaseous substances. Nagel (1894) was of the opinion that chemical stimulation in aquatic animals could only be mediated by taste. Since then many investigators attempted to differentiate between the sense of smell and taste in fishes (Von Uexkull, 1895; Herrick, 1908; Parker, 1910, 1911, 1912, 1922; Sheldon, 1909, 1911; Copeland, 1912; Olmsted, 1918 and

Strieck, 1924). The most convincing evidence of the sense of smell in fish was obtained by Strieck (1924).

Uexkull (1895) contradicted the idea of Nagel (1894) by conducting his experiments on the shark (Mustelis canis). He observed that the shark, whose epithelial lining of the olfactory sac is operated, locate their food with great difficulty in comparison to those having intact olfactory epithelium. The operated shark use to swallow sardines heavily coated with quinine which was soon discarded from the buccal cavity.

Herrick (1908) in his researches of nervous system of the olfactory and gastatory senses, distinguished these two senses on the basis of the reception of stimulation. He demarcated the olfactory sense as a distant receptor whereas the gastatory is localized in the oral cavity and can be perceived only by the touch of the material of gastatory sense.

The different experiments of Parker (1910, 1911), Sheldon (1911) and Copeland (1912) on fishes have proved that the sense of olfaction plays an important role in locating the food material in aquatic medium. So the wrong idea of Nagel (1894) was further contradicted.

Sheldon (1911) noted that there was no basic difference in the sense of olfaction of fishes and other

vertebrates. Parker and Sheldon (1913) observed that the sense of olfaction and taste differ not only with regards to the quantity of stimulating substances but also in their concentrations. Olfactory organs in fishes perceive very dilute solution while gastatory organ with more concentrated mixtures.

The existence of the sense of smell in fishes was very convincingly proved by Strieck (1924). He observed that trained minnows can very easily discriminate between the odorous and taste substances. However, after the removal of forebrain the trained fishes were unable to discriminate the odorous substances.

Earlier investigators who worked on the anatomy of the olfactory organs of fishes are those of Bateson (1889), Burne (1909), Allison (1953), Hagelin and Johnels (1955), Kleerekoper and Erkel (1960), Trujillo-Cenoz (1961), Johnson and Brown (1962), Kubiak (1962), Branson (1963), Gooding (1963), Pfeiffer (1963, 1964), Bannister (1965), Moulton and Beidler (1967). The generalised review on the anatomy of the olfactory organs of fishes have been published by Kleerekoper (1969), Teichmann (1954) and Hara (1975).

The recognised Indian workers who carried out their researches on the anatomy of the olfactory organs of Indian teleosts are Kapoor and Ojha (1972a,b, 1973a,b) and Ojha and Kapoor (1971, 1972, 1973a,b and 1974). Their two papers have

also been appeared on the histology of the olfactory epithelium of Labeo rohita (1973) and Channa punctatus (1974). But except above authors and to some extent Singh (1972), Rahmani and Khan (1980) no amountable work on the histology of olfactory organs of Indian teleosts has been conducted so far.

Reviewing the existing literature it is found that the work on the olfactory organ of the European fishes has been done to some extent but little work has been carried out on Indian teleosts. Consequently the present work on histomorphology of the olfactory organs of some fresh water Indian teleosts has been undertaken broadly to provide a basis for the further study on this important aspect. Therefore, the present study of the olfactory organ gives a comprehensive account of the structure, shape and size of the olfactory rosette, lamellae, nasal cavity and the accessory nasal sacs (wherever present). The position of rosette in relation to cranial bones and varied structure of nostrils has also been taken into consideration. The topographical study of the relationship of brain and olfactory rosette has also been studied from anatomical point of view. The areas of both the rosettes were calculated and compared with the areas of both the retinae for making the approximate assessment of the sensitivity of olfactory and optic surfaces (Teichmann, 1954). Cellular components of olfactory epithelium, nerve and blood

supply have also been studied in detail from histological point of view.

The present author carried out his research work on the topic, "Histomorphological studies of olfactory organs of some fresh water<sup>Indian</sup> teleosts". The selected fishes are: Nandus nandus (Hamilton), Ompok bimaculatus (Bloch ), Notopterus chitala (Hamilton) and Oxygaster bacaila (Hamilton). The habit, habitat, distribution and diagnostic characters of these fishes are given below.

#### Nandus nandus (Ham.)

Nandus nandus is distributed in fresh and brackish water of India, Pakistan, Bangladesh and Burma. The family Nandidae is very primitive and once it was widely distributed. Most of the members of this family hide under rocks or in similar cave like places from where they dash out to capture their prey. Male usually guards the eggs and fry until they are able to swim freely. N. nandus is common in ditches and in undated fields where it preys on small cyprinidae. It is greenish brown with brassy reflection, vertically marbled with three broad patchy bands and a fourth crosses the free portion of the tail or occasionally there exists a black blotch. Some narrow dark bands radiate from the eye. Narrow bands of spots across the soft portions of the dorsal, anal and the caudal fins. N. nandus attains atleast 7 inches in

length. One of the most remarkable feature of the fish is large mouth which is equipped with extensible jaws that enable them to engulf other fishes atleast half of their own size. They frequently extend their jaws in what appear to be a prodigious yawn (Herald, 1961). It is exceedingly tenacious of life.

Ompok bimaculatus (Bloch)

O. bimaculatus is found in fresh water of India, Pakistan, Ceylon, Burma to Java, Sumatra, Borneo Malaya, Siam and Indochina. In India it is found particularly in larger rivers. It is more common in Madras on the Malabar coast and in the cauvery river system. Its colour is silvery but varies with the habitat. It may be white yellow or greenish brown shot with purple. A black spot is found on the shoulder behind the gill opening and above the middle of the pectoral fin. The body is laterally compressed. The anal is banded with a blackish edge. Caudal is deeply forked, lobes sharp pointed and the fish attains a length of one foot and half. It is carnivorous in habit feeds on insects and their larvae. Fishes of this genus are usually excellent as food and from their quality have been termed as 'Butter fish'.

Notopterus chitala (Ham.)

Genus Notopterus includes N. notopterus and N. chitala. They are commonly known as 'knife fishes' or 'feather backs'

and can easily be identified by a long anal fin which begins just behind the head and extends along the under surface of the body to the tip of the tail, tail fin as such is not evident. In the centre of the back is a small slender, dorsal fin which derives its name as 'feather back'.

N. chitala is commonly found in the western part of India, Pakistan, Burma, Siam, Malay, Archipelago and Philippines, attaining at least 4 feet length. Brackish water localities are also inhabited by the fishes of family Notopteridae. Fishes of this family are bottom feeder and are found in a quite weedy reaches of great rivers in flood plains and stagnant water. They rest during the day singly or in shoal in shelter of old stem and thick floating plants. During the night they move insistantly, close over the bottom, seeking small prey such as insects, fish fry, fingerlings, small fishes, frogs, tadpoles etc.

N. chitala is comparatively shy but more active than N. notopterus. It tends to be quarrelsome in aquarium and can not be kept with other fishes, being a heavy bodied fish and harmful to other smaller species. However, it lives quite peacefully with other fishes provided they are not considerably smaller.

The colour of the body is superiorly coppery brown with about 15 transverse silvery bars joining over the back, sides are silvery. Fins stained with greyish spots, which

are like black stars in the caudal region, placed in a single or double row close to the anal fin and sometimes extending the whole length of its base. Upper profile of the head is deeply concave and snout is rather prominent. The belly is uncommonly rich and well flavoured but the back contains numerous small bones and a strong prejudice exists against using this fish as food, owing to its being supposed to live on human carcasses. Local governments are trying hard for its successful spawning in the local streams and confined waters.

Oxygaster bacaila (Ham.)

O. bacaila is found in fresh waters of India (except Malabar, Mysore, Madras and parts of the Decan) and Pakistan, attaining at least 7 inches in length. This species is restricted more to the valley of Ganges and its affluent streams, also to the Punjab and down the Indus. This genus is commonly called as 'Chilwa'. The smaller varieties feed on mosquito larvae throughout the life. They have upturned mouth and feed on the surface water. In this fish cleft of mouth reaches to below first fourth of suborbital ring. The colour of the body is uniform silvery. These are delicate fishes and the larger species are used as food.

The sense of olfaction is a long range type of reception (Marshall, 1967) in which informations are gathered from a distance like lateral line system. At the same time

a fish may stumble upon a sense of odours as it swims around its habitat. Capability of differentiating the water of different rivers by smell has also been reported in fishes. Teichmann (1957, 1959) demonstrated that trout could perceive the presence of phenyl ethyl alcohol at a concentration  $9.9$  to  $10^{-9}$  m. He reported that perception power varies markedly from species to species. Stimulatory sensation of the surrounding environment is collected by these receptors, through the external medium and transmitted to the central and peripheral nervous system for the realisation of the sensation. The environmental medium, in which an animal lives, plays an important role in transmitting the stimuli upto receptor concern, such as air for the terrestrial and water for the aquatic animals.

Sophie Pereyaslawzef (1876) studied the anatomy of the olfactory organs of Solea impar and Lophius piscatorius. This study was coarse and no full paper was available on the said topic.

Blaue (1884) studied the anatomy of the olfactory chamber and rosette in Belone, Exocoetus, Esox, Umbra, Cottus, Gobius and Gadus. This important paper was published under the title of the olfactory membrane in fishes and amphibia. The generalised anatomy of olfactory pit and rosette was discussed.

Weidersheim (1887) selected Tetradon nigropunctatus, T. immaculatus, T. pupa, T. paradalis and Diodon maculatus to study the olfactory organs. He published an interesting account of the stages of degeneration of olfactory organs of Plectognaths and their change from a simple cavity to a split tentacle which is fully exposed to water.

The olfactory organs in fishes are represented by a pair of olfactory pits which are located on the dorsal surface in Sturgeons and bony fishes, in sharks and rays on their ventral surface of the head. Olfactory pit is lined by olfactory epithelium which is generally raised in the form of serial folds or lamellae. Generally each nasal pit opens out side by two openings, anterior inlet and posterior outlet. In some species posterior outlet directly opens into the mouth. In Chimaera monstrosa the olfactory chamber is communicated dorsally with the naso-oral groove. The naso-oral groove is formed due to the extension of two external nostrils along the upper lid towards the mouth cavity. When the mouth is closed, water passes through the external nostril along the naso-oral groove and through the internal nostril into the mouth cavity. It is reported by Holl (1973) that since the olfactory chamber communicates dorsally with the naso-oral groove it is always supplied with water.

The olfactory organs are diversely developed. At one extreme they are well developed such as in elasmobranchs

and most of the eels and at the other they are poorly developed such as in pike, flying fish, stickle back, pipe fish, angle fish. Frisch (1941) denominated the former group of fishes as macrosmates and the latter microsmates on the basis of the olfactory ability. This classification is also accepted for the other groups of vertebrates.

It has been reported that there is a wide variation in the location, size, structure and degree of development of olfactory organ in teleostean fishes. Burne (1909), Liermann (1933), Matthes (1934), Teichmann (1954), Holl (1965), Singh (1972), Zeiske (1973, 1974) have presented a generalised account of the olfactory organ of fishes, although there is no extensive review of the nasal anatomy. However, Laibach (1937), Eaton (1956), Johnson and Brown (1962), Branson (1963), Pfeiffer (1963, 1964, 1968, 1969), Devitsyna (1972), Kapoor and Ojha (1972, 1973a, 1973b), Ojha and Kapoor (1971, 1972, 1973a, 1973b, 1974) and Rahmani and Khan (1977, 1980) carried out their studies on a single species of teleost fishes. Kleerekoper (1969) and Hara (1975) published a review on the anatomy of the olfactory organ of fishes and presented critically the anatomical peculiarities of the olfactory organs of some groups of fishes.

Hara (1975) noted that the paired olfactory pits are usually situated on the dorsal side of the head. The eels possess long olfactory pits which extend from tip of the

snout to the eye orbits. Such fishes with elongated pit have most acute sense of smell. The olfactory pits, contrary to the above findings, are totally abolished and nasal flaps are exposed to the water in tetradontiformes. Such fishes are provided with very regressed capacity of sense of smell.

Marshall (1967) gave a detailed account of the olfactory organs of bathypelagic fishes and found that males of such fishes, for example, Ceratoidea, Stomatoidea etc. have large olfactory organs but in females they are small or regressed. Moreover, in few groups (Lyomeri, Cyema, Avocettina etc.) olfactory organs are extremely degenerated in both the sexes. Bertelsen (1951) and latter Marshall (1967) reported that macrosmate males are attracted to the scents of their much larger females. The scent is supposed to be biochemically peculiar to each species. The slow moving females leave behind them a specific scent which is perceived and followed by the searching males.

Bateson (1889) in a paper of sense organs and perceptions of fishes, besides some highly interesting physiological notes, gave details of the structure of the nostrils and olfactory rosette in various common species of fishes. He was assigned by the Council of Marine Biological Association, London to study the perception of fishes. He pointed out (i) the tubular character of anterior nostril in few fishes that hunt their food by scent (Motella, Cobitis,

Solea, Conger, Anquilla, Lepadogaster), (ii) the valvular mechanism of the posterior nostril in certain flat fishes, (iii) the main type of the structure of rosette; elongated in eels, oval in the majority of fishes or circular in Cottus and exceptional type in which the leaflets are arranged in parallel series in a single row (Pleuronectes and Hippoglossus).

On the basis of the arrangement of the plates or lamellae in the olfactory rosette, Bateson (1889) differentiated four types of olfactory rosette in the following manner:

- i) In the skate and dog fish the plates are arranged in a radiating manner on the inside of a hollow capsule, like the septa of an orange.
- ii) In the conger and eel, the lamellae are arranged in two rows on each side of the central raphe.
- iii) The most common arrangement is found in the third type of olfactory organ, where the plates are fitted together in a radiating manner, forming a convex eminence in the olfactory chamber. The whole organ is either circular (as in Cottus and Motella mustela) or elliptical (as in the mackerels); In all the teleosteans mentioned in this discussion, most of the plates are placed at right angle to the long axis of the body and each organ essentially consists of two rows of such plates united in the middle.

- iv) In Pleuronectes spp. and Hippoglossus vulgaris an entirely different arrangement is found. In these fishes, the lamellae are arranged in a single row which lie parallel to the long axis of the body.

On the basis of the olfactory behaviour, Bateson (1889) divided the fishes into two categories: (i) in this group of fishes which hunt their food with the help of vision, no reaction to the smell of food was observed. Such fishes don't feed at night, (ii) second group of fishes seek their food by the smell, vision was never used for this purpose. He concluded that all the fishes hunting by smell are to some extent nocturnal animals; the groups of the fishes studied by him are those of eel (Anquilla anquilla), marine barbot (Gaidropsarus tricirritus and G. mustela), common sole (Solea vulgaris, Lepadogaster govanii), dog fish (Scyliorhinus canicula), ray (Raja batis), African lung fish (Protopterus annectens) and starlet (Acipensor ruthunus).

Burne (1909) studied the olfactory organs of 52 genera belonging to 32 families of teleostean fishes. He observed that olfactory chambers comparatively differ little in shape and size. In nearly every case, olfactory rosette occupies a constant and fixed position with regard to the bones of the skull, being lodged in a hollow ethmoid between the point of articulation with the palatine and the lacrymal bones.

Burne (1909) also reported that the nostrils are perhaps the most variable part of the olfactory organ but their variability is correlated least with natural affinities of the fishes. The position of the anterior nostril directly above the rosette is most common because its opening helps to facilitate the incurrent water to move over the olfactory lamellae. The anterior nostril is generally tubular especially in lower teleosts. In certain groups of fishes, notably the Cyprinidae and Gadidae, the hinder wall of the tube becomes elevated to form a valvular flap and in other groups or genera (Esox, Merluccius, Clupeidae, Salmonidae) the flap is augmented or replaced by a similar downward prolongation or curtain that dips into the olfactory cavity above the centre of rosette. Such studies led Burne (1909) to identify four types of anterior nostrils: (a) simple perforation, (b) tubular, (c) with posterior hood, (d) with internal curtain.

Similarly, the shape and the size of the posterior nostril also seem to depend little upon natural affinity. It may be of two types: (a) either a simple perforation flushed with the surface of the skin of head, or (b) it is a slit or pin-hole which remains closed by valves. The outline of the posterior nostril is either circular, oval or crescentic but rarely tubular. The presence of circular or oval form of posterior nostril is observed in many groups but it can not

be treated as a characteristic for those groups where only one nostril is present as in Gasterosteus, labidae and chromidae.

In the fishes, which possess accessory nasal sacs for forcibly drawing the water through the olfactory chamber by pumping mechanism, the valvular condition of nostril is recorded. The accessory sacs can be separated into three series, (i) a single sac directed anteriorly from either above or below the rosette, (ii) a single sac directed posteriorly towards the eye orbit, (iii) two sacs (ethmoidal and lacrymal nasal sacs) with very definite relation to the ethmoidal and lacrymal regions of the skull.

Burne (1909) distinguished four types of olfactory rosette in teleostean fishes and classified them in columns and types of Bateson (1889); first type of rosette is oval in shape and is very common in occurrence in the fishes studied by him (Bateson's, 1889 rosette type 3; Burne's, 1909 rosette column I); second type of rosette is circular in shape and is found in Cyclopterus, Bovichthya, Cottus, Esox, Orestias. It is provided with lamellae radiation in all directions (Bateson's, 1889 rosette type 3; Burne's, 1909 rosette column III); third type of rosette is elongated with their lamellae arranged in parallel series at right angle to it (Bateson's, 1889 rosette type 2; Burne's, 1909 rosette column II). In most of the eels, to a less extent in siluroids

and soles such rosettes are observed. Fourth type of rosette is with transverse axis to the internarial line and the lamellae are attached to its posterior border in parallel series (Burne, 1909 column IV). Such rosettes are observed in Ophiocephalus, Hippoglossus and Pleuronectes. Species with elongated rosette have well developed olfactory faculty because the number of olfactory lamellae is numerous. Fishes with rounded rosette normally have only a few lamellae and usually show poor olfactory perception. Species having oval rosettes are most common and stand intermediate between the two.

Teichmann (1954) divided the fishes into three groups on the basis of the development of olfactory and visual faculties: (i) eye nose fishes in which both olfactory and visual faculties are equally developed (Phoxinus, Gobio), (ii) eye fishes with a predominantly developed optic faculty (Esox, Gasterosteus) and nose fishes with a predominantly developed olfactory faculty (Anquilla and Lota). He also made an attempt to calculate and compare the retinal and olfactory area on the basis of which he categorized the fishes into microsmatic (eye fish) and macrosmatic (nose fish).

Teichmann (1954) took into consideration the classification of Bateson (1889) and Burne (1909) and proposed as follows: The oval rosette (Bateson's type 3, Burne's rosette column I) with his 1st group of eye nose fishes; the circular

rosette (Bateson's type 3; Burne's rosette column III) with his 2nd group of eye fishes; and the elongated rosette (Bateson's type 2; Burne's rosette column II) with his 3rd group of nose fishes. However, Ojha and Kapoor (1971, 1973b, 1974) who studied the olfactory organ in Garra gotyla (1971), Glyptothorax telchitta (1973b) and Sisor rhabdophorus (1974) questioned the feasibility of linking the olfactory faculty of a fish exclusively with such a morphological criterion as the shape of rosette. They observed, for example, in Garra gotyla, that this fish has a very well developed olfactory faculty but it possesses an oval type of rosette. Thus according to Teichmann's classification Garra gotyla should have an elongated rosette.

The data regarding the number of lamellae present in a fish were collected by Teichmann (1954). He concluded that the number of lamellae increases to some extent with the length of fish. In addition to the formation of new lamellae, each lamella increases in its size. Thus the area of olfactory epithelium of individual fish is considerably increased with the formation of new lamellae and by the growth of those already present. For the first time Teichmann (1954) reported the presence of secondary lamellae in rainbow trout. However, he confused them as the artifact of preservation.

Pfeiffer (1963), Bertmar (1972), Hara et al. (1973), Bashor et al. (1974) were of the opinion that the secondary

lamellae ultimately increase the area of olfactory epithelium. However, it was observed that secondary lamellae are devoid of receptor cells.

Great variations are reported in the arrangement of the folds of olfactory epithelium which vary from species to species. It is commonly observed that rostro-caudally elongated raphe is present in most of the fishes which acts as the place of attachment of olfactory folds in the central part of olfactory rosette. The variation in the number of lamellae in few species was reported by Wunder (1957) as 2 in Gasterosteus aculeatus; 9-18 in Esox lucinus; 11-19 in Thymellus articus; 14-18 in Salmo gairdneri; 30-32 in Lota lota; 60-90 in Anquilla anquilla; Shibuya (1960) and Pfeiffer (1964) recorded 80-90 and 230 lamellae in Channa argus and Haplopagarus quentheri respectively. Hara et al. (1973) recorded 12-14 and 12-16 lamellae in Salvelinus fontinalis and Coregonus clupeaformis respectively. It is critically studied by Kapoor and Ojha (1972a, b, 1973a, b) and Ojha and Kapoor (1971, 1972, 1973, 1974) that the lamellar development is always from anterior to posterior side. It is, therefore, concluded that posterior lamella is oldest and largest, no addition of lamella is reported to the lateral ends. Number of lamellae in a fish depends upon the size of the animal.

The shape of lamellae is also variable from species to species. In some cases like Salmonidae, Clupeidae, the

lamellae bear linguiform processes where the suppression of the peripheral part of the lamella leads to the exaggeration of the linguiform process. Suppression of linguiform process causes the lamella to become gently curved or with straight free borders, as seen in Mormyrus, Clarias, Esox and Orestias. In Mugil, Perca, Pegelus or Sphyræna, the lamellae are sharply convex but triangular in eel. In Percesoces the lamellae are entirely absent. The degeneration of nose is noticed in Lophius where few lamellae are present which are parallel to each other.

For the first time Scot (1887) observed the accessory nasal sacs in fishes believed them to be homologous with Jacobson's organs of higher vertebrates. Kyle (1899) described accessory nasal sacs in connection with the true olfactory chamber and laid stress on the fact that in several species of Pleuronectids (Hippoglossus, Pleuronectes, Rhombus with the exception of Solea and Cynoglossus), the sacs secrete mucous and are not simple reservoirs but producing water currents by their alternate expansion and contraction. Lubosch (1905) (vide Burne, 1909) regarded them as the degenerate caudal region of the olfactory epithelium.

Eaton (1956) reported in centrarchid fishes that the epithelial folds radiate in spoke like form from the region approximately under the anterior nares. He named the two accessory sacs as medial and lateral pouches. He also

suggested that they are mechanical rather than olfactory in function. Liermann (1933), Gooding (1963) and Watling and Hilleman (1964) are of the opinion that though the accessory sacs are linked with the olfactory chamber but they don't have the sensory epithelium. On the other hand, Johnson and Brown (1962) in Sebastodes melanops reported that the two sacs are the extension of the epithelial cavity and lie in close contact with jaw bones.

Kapoor and Ojha (1971a), Ojha and Kapoor (1972), Hara (1975) and others also considered that the accessory sacs help in bringing the water current through the olfactory chamber.

The accessory sacs can be separated for convenience into three series: (i) a single sac directed anteriorly from either above or below the rosettes, (ii) a single sac directed posteriorly towards the eye orbit, (iii) two sacs (ethmoidal and lacrymal nasal sacs) with very definite relation to the ethmoidal and lacrymal regions.

The idea of water circulation through the olfactory chamber was given by Solger (1894). He pointed out that by alternate expansion and contraction of the accessory sacs, water flows in and out of the olfactory cavity, and the movements of the olfactory sacs are synchronous with the respiratory movements of the fish.

Pipping (1926) observed that the olfactory capacity is very much related with the nature of transportation of water circulation through the olfactory chamber. On the basis of this relationship he divided the fishes into four groups: (i) first group include those fishes in which the flow of water passes through the olfactory sac only at the time of the forward movement of fish, (ii) in the second group movement of water is caused by the pumping action of accessory sacs, water enters and exit through both the nostrils i.e. unidirectional flow of water is absent, (iii) in the third group water movement is unidirectional, created by the pumping action of the accessory sacs synchronized with the respiratory action supplemented by the ciliary movement of the olfactory epithelium, (iv) in the fourth group of fishes water circulation is carried out through the olfactory chamber along with the respiratory movement supplemented by the ciliary action of olfactory epithelium. The passage of water current is unidirectional. He further specified that fishes belonging to fourth group have highly developed sense of olfaction which plays significant role in the recognition of food. In the fishes of first and second groups, olfaction is weakly developed and does not contribute in the location of food in the aquatic medium.

According to Doving et al. (1977), Doving and Thommesen (1977) the water circulation through olfactory chamber is technically denominated as Isosmates and

Cyclosmates types. In the former ciliation of olfactory epithelium is responsible for the water circulation through the olfactory chamber whereas in latter compression and expansion of the accessory sacs, in relation to skull bone, bring about the transportation of water through the olfactory epithelium.

The denomination of Doving et al. (1977) in relation to water transportation through the olfactory chamber is further corrected by Derivot and Godet (1979). They clarified the isosmates nomenclature of Doving et al. (1977) in the form of Heterocyclosmates and Autocyclosmates. The former fishes are dependent on respiratory movement for the circulation of water through the olfactory chamber, whereas in latter ciliary action is solely responsible for creating the water current through the olfactory chamber.

Rahmani (1979) in addition to Doving et al. (1977) further elaborated the classification of fishes with regard to the circulation of water through the olfactory chamber and he put forward another denomination as amphisomatic besides cyclosmates and isosmates. Here water transportation is brought about by the ciliary movement as well as the pumping activity of sacs. The remarkable observation is the presence of window in some lamellae of Colisa fasciatus which facilitates easy water circulation through the olfactory rosette.

Rizvi et al. (1984) studied the olfactory organ of a fresh water fish, Mystus vitatus and recorded this fish as

macrosmatic species with predominantly developed olfactory faculty. They reported unidirectional entry of water in the olfactory chamber which is carried out by the ciliary movement of olfactory lamellae.

Malyukina et al. (1969) reviewed the work on the morphology and functional peculiarities of the olfactory organs and significance of olfaction in feeding, schooling and migrating behaviour.

Ojha and Kapoor have described in detail the morphology and functional anatomy of the olfactory organs of some Indian teleosts: Garra gotyla (1971), Wallago attu (1972), Labeo rohita (1973a), Glyptothorax telchitta (1973b) and Sisor rhabdophorus (1974). Moreover, Kapoor and Ojha described other fishes: Muraena undulata (1972a), Channa punctatus (1973a) and Cynoglossus oligolepis (1973b). They concluded that when the anterior and posterior openings of the olfactory organ are separated by some distance, the anterior opening is always tubular. Bateson (1889) reported that the tubular anterior openings are characteristic of fishes having a well developed olfactory faculty. However, Kapoor and Ojha (1972, 1973a,b) and Ojha and Kapoor (1971, 1972, 1973a,b and 1974) did not correlate their openings with respect of behaviour.

Waghray (1986) observed sexual dimorphism in electric ray, Narcine timelel, based on the shape and size of

the olfactory organ. He found kidney shaped and more rounded olfactory organ in male while it is slightly elongated and narrow in female. Linguiform process of lamella is more prominent in male as compared to the female.

Bertmar (1972c) observed that comparative study of one and the same structure or organ in related species of different ecological habitats may provide information on the detailed mechanisms of their function. Conversely, knowledge of how certain structures tend to undergo morphological modifications due to different functional demands may give us valuable information on the ecology of a species only by studying its structure. Bertmar (1972c) has termed such findings as 'Ecostructural studies'.

Our knowledge pertaining to histology of olfactory organ is very meagre. However, some of the important references in this regard are those of Hopkins (1926), Kolmer (1927), Allison (1953), Trujillo - Cenoz (1961), Branson (1963), Gemne and Doving (1969), Kleerekoper (1969), Ojha and Kapoor (1973), Kapoor and Ojha (1972c) and Hara (1975). Our existing knowledge reveals that the plan of olfactory epithelium of the fishes is not very much different as compared to those of other vertebrates; receptor cells, supporting cells and basal cells. The presence of sensory and supporting cells in the sensory epithelium of fish as in other vertebrates was also observed by Grimm (1873), Dogel

(1886) and distinguished three forms of sensory cells: filamentous, rod shaped and cone shaped. In some species of Anquilla and Myxocephalus, large flask shaped mucous cells are observed which are interspersed among the supporting cells. The presence of mucous cells in the olfactory epithelium of other vertebrates shows variation in the minor detail within a particular organ. They are filled with secretory substance which is seen extruded out in the inter-lamellar spaces.

Popova (1966) also reported the presence of mucous cells among the supporting cells. In addition to usual cell types, new cellular elements such as secondary neurone or spindle shaped cells and primary neurones or rounded cells have been identified by Kapoor and Ojha (1972c) and Ojha and Kapoor (1973) in Channa punctatus and Labeo rohita respectively.

Bertmar (1972a,c) also described cell populations and dynamics in olfactory epithelium of Sea trout and the turnover of the cells within the epithelium. He observed that some blastema cells tend to undergo differentiation into primary supporting cells which give rise to ciliated, non-sensory and microvillus cells. Other blastema cells become elongated and give rise to primary receptors. In addition to the usual cell types, Bertmar (1972b, 1973) reported the presence of labyrinth cell in Baltic sea trout, which is unique among the vertebrates. He suggested that these cells

probably help to maintain an optimum ion balance for species migrating from sea to fresh water and vice-versa.

Davitsyna (1972) compared two marine species, Sea cod (Gadus moruha) and Novaga (Eliginus novaga) with a fresh water member of the family Gadidae, Barbot (Lota lota) on the basis of the histological structure of the olfactory epithelium and bulb. He characterised quantitative distribution of receptor cells, along the surface of folds, is irregular in all three species and this is reflected in their concentration in some parts and their thinning out in others. However, the general pattern of the quantitative distribution of the sensory element over the olfactory fold is characterised for each species.

Thornhill (1972) reported the structure of accessory olfactory organ of Lampetra fluviatilis which consists of cluster of interconnected vesicles in tenous connection with the exterior medium via the cavity of olfactory organ. The wall of the vesicle is composed of two types of cells which are designated as light and dark cells, primary sense cells and supporting cells by Hagelin and Johnels (1955) and Thornhill (1972) respectively. The primary sense cells which are responsible for the sensation of smell, are provided with peripheral nuclei with their axons directly passing to brain. They differ from olfactory sense cells in the size and number of cilia. It is, therefore, concluded that accessory sense

organ of *Lampetra* is capable of responding to 'special kind' of chemical stimulus. Contrary to the findings of others, Thornhill (1972) suggested that the accessory olfactory organ is morphologically similar to the olfactory epithelium.

Recent researches dealing with the epithelium of olfactory organ of fishes based on electronmicroscopy reveals that four types of cells are present in olfactory epithelium of *Neoceratodus forsteri* i.e. olfactory receptor cells, supporting cells, nonsensory ciliated cells and basal cells. Goblet cells may also be present but their shape, size and secretory habit differ variably from species to species. The essential features of the olfactory receptor cell of *Neoceratodus* are the presence of microvilli and cilia (Theisen, 1972).

Zeiske et al. (1976) studied the epithelium of the olfactory organ of the cyprinodontidae species by transmission and scanning microscopy. The relatively flat floor of the organ is covered by sensory and non-sensory epithelia. Nonsensory epithelium separates the distinct area of sensory epithelium. Difference between the two olfactory organs of *Xephophorus heleri* and *Aplocheilichthys lineatus* was found to be related to the topography and quantitative distribution of epithelia. The nonsensory stratified squamous epithelium contains numerous goblet cells and surface cells with microridges. The sensory epithelium

bears basal supporting and two types of sensory cells i.e. ciliated and microvillus receptor cells.

Yamamoto and Ueda (1977, 1978a,b,c,d,e,f) described the orders Salmoniformes, Clupeiformes, Cypriniformes, Gasterosteiformes, Channiformes, Symbranchiformes, Anguilliformes, Myctophiformes and adopted scanning microscopy process in describing ultramicroscopic structures of the olfactory epithelium of the representatives of the above orders. Their main stress was on the different types of ciliation and intercellular contents of the cells of the olfactory epithelium. They described following types of cells on the basis of their surface specialisation, cells bearing many long cilia on wide and flat surface (type I ciliated cells); those bearing several short cilia which project radially from the round cell apex (type II ciliated cells); those bearing no cilia but a tuft of numerous microvilli (microvillus cells); those bearing neither cilia nor microvilli but protruding as a simple rod from the surface (rod cells). Their internal structures are reported to have similar internal microorganelles.

On the basis of surface specialisation in the olfactory epithelium Yamamoto and Ueda (1978e) reported that fish with dense cilia arising from type one ciliated cells are believed to have predominantly developed olfactory sensitivity such as eels (Schulte, 1972; Yamamoto and Ueda, 1978c), Salmons (Bertmar, 1972; Yamamoto and Ueda, 1977) and

cod (Lowe and MacLeod, 1975). Contrary to it fishes are having less developed olfactory sensitivity where epithelium lacks type one ciliated cells and cilia are dispersed into small islets such as Atheriniformes (Zeiske et al., 1976), stickle backs (Bannister, 1965; Yamamoto and Ueda, 1978d).

Sharma (1981) reported that the olfactory epithelium of lamellae exhibits cellular activities like budding, detachment, cellular extrusion, curving and the migration of mucous secretory goblet cells in the fishes choosen in his research work.

Singh and Singh (1986) carried out their investigation on the olfactory organ of four hill stream fishes. They reported that the olfactory epithelium is composed of ciliated cells, microvillus cells, supporting cells and pigment granules. Rod cells were found only in the lamellae of Schizothorax richardsonii. Apertures or holes and tufts of microvillus cells were also observed in the olfactory lamellae of Puntius chilinoides.

Kashiwayanagi et al. (1987) reported the changes in membrane potential and membrane fluidity in response to various odorants in a suspension of Porcine olfactory mucosa.

Doroshenko and Motavkin (1987) observed variations in number and arrangement of the olfactory rosette folds as well as in olfactory epithelium which they named as receptory

and indifferent epithelium. They further pointed out that olfactory epithelium interspecifically varies greatly in the arrangement of receptor and secretory cells. Doroshenko and Motavkin (1987) categorically identified flagellar cells which may be olfactory and sensory in nature. Former bears large flagellum whereas latter comparatively less prominent flagellum with more complex structures. Both these investigators worked out secretory cells in the form of black ostia which bear multicellular olfactory duct.

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## MATERIAL AND METHODS

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## MATERIAL AND METHODS

Large number of Notopterus chitala of different sizes were obtained from Jamni Dam, district Lalitpur, Uttar Pradesh. Oxygaster bacaila and Ompok bimaculatus were collected from Pahuji Dam near Simardha village, Nandus nandus from ditches near Baruasagar Dam, district Jhansi, Uttar Pradesh.

The fishes under investigation were collected in living condition and were kept in Aquaria for experimental use. The dead specimens of different sizes were also procured from local fish market.

For the study of cranial components related to lacrymal and ethmoidal regions, dried skulls were prepared by removing scales and skin of the head and then treated with 4% KOH for 2-5 days depending upon the thickness of the tissue. Subsequently muscles were removed with the help of forceps and brushes. The cleaning and bleaching were done by using benzene and hydrogen peroxide. The skulls thus obtained were kept for drying for a day. The observations were made under stereoscopic binocular microscope. Diagrams were drawn with the help of Prism Camera Lucida. Alizarine transparencies of all specimens were prepared by Hollister's technique (1932) to study the cranial architectural pattern in relation to olfactory chamber.

The olfactory and retinal areas were calculated by the Teichmann (1954) method. Prior to the separation of olfactory lamella, the rosettes were kept in 70% alcohol, which causes stiffness in the lamellae. This allows easy detachment of the lamellae without any damage from raphe and the floor of the olfactory chamber. First of all the rosette was cut into two equal halves through the raphe by sharp blade and then lamellae were gradually separated one by one from anterior side. Separation of lamellae in N. nandus where raphe is absent, was easier than those having raphe (i.e. N. chitala, O. bimaculatus and O. bacaila).

The lamellae were mounted temporarily in glycerine and their diagrams were sketched at a known magnification. Their actual areas were measured by the planimeter. The total area of one half is multiplied by two and thus the value of area of one rosette is calculated. But in N. nandus the area was not multiplied by two to get the value of olfactory area of one rosette due to absence of raphe. Same is doubled for getting the value of areas of both the rosettes of a fish. For anatomical studies, the fishes of different sizes were fixed in 10% formaline and Bouin's fluid. Heads were dissected from dorsal side under stereoscopic binocular microscope for the study of olfactory organs and their relationship with the brain.

The area of the eye was measured by planimeter as well as by applying  $\pi r^2$  formula where 'r' is the radius of the eye.

Ecological coefficient of each species by area method were calculated by the following formula:

$$= \frac{\text{Total area of olfactory lamellae (both the rosettes)}}{\text{Total retinal area (both the eyes)}} \times 100$$

Similarly ecological coefficient calculated by brain lobe method can be drawn by the following formula:

$$= \frac{\text{Length of telencephalon}}{\text{Length of mesencephalon}} \times 100$$

For histological studies the olfactory rosette and accessory sac (wherever present) were taken out from the narcotized specimens and were fixed in Bouin's fluid for 6-24 hours depending upon the tissues. Transverse and horizontal sections were cut at 6-8  $\mu\text{m}$  in thickness and stained with Mallory's aniline blue collagen stain and Delafield's haematoxylin and then counterstained with eosin.

To study the water circulation through the olfactory chamber alizarine red solution was injected by hypodermic syringe from both anterior and posterior nasal openings for demonstrating the ingress and egress of the water. It was observed that the red solution was coming out from posterior nasal opening, establishing unidirectional flow of water (from anterior nasal opening to posterior).

Similar results were also obtained by injecting Carmine and chalk particles when it was repeated on preserved specimens in which jaws were mechanically opened and closed.

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OBSERVATIONS

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Fig. 1. Lateral view of the head of N. nandus.

Fig. 2. Dissection of the head of N. nandus from dorsolateral side to show the rosette insitu.

ANT. NAS. OP.	-	Anterior nasal opening
EY.	-	Eye
INT. LAM. SP.	-	Interlamellar space
LAM.	-	Lamellae
POST. NAS. OP.	-	Posterior nasal opening
RIM.	-	Rim
W. OLE. CHAM.	-	Wall of olfactory chamber

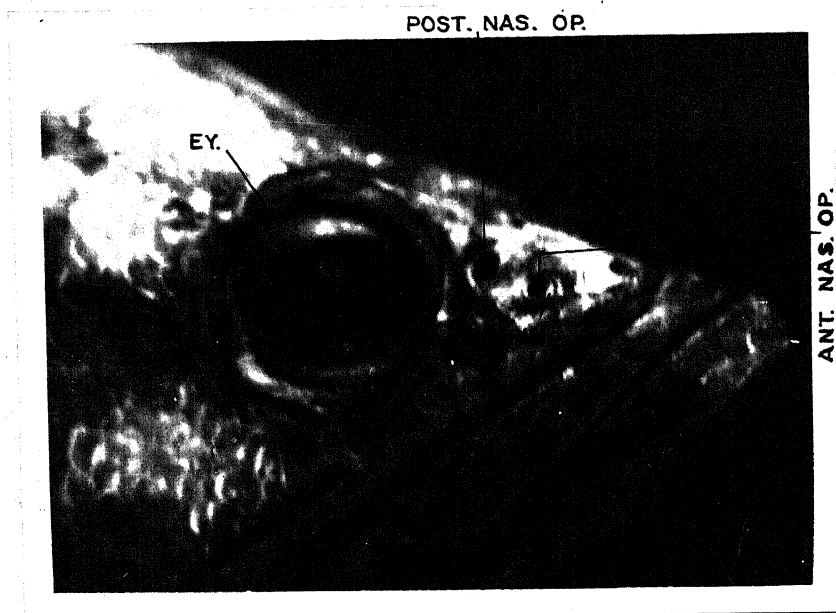


FIG. 1.

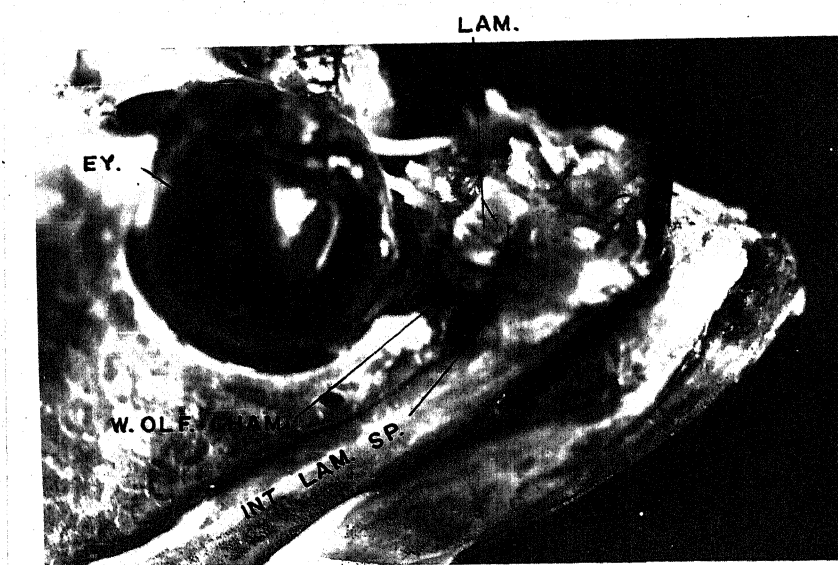


FIG. 2.

- Fig. 3A. Diagram of the lateral view of head of N. nandus
- Fig. 3B. Diagram of the olfactory chamber to show the position of anterior and posterior nasal openings in N. nandus
- Fig. 3C. Diagrammatic sketch of the olfactory chamber of N. nandus to show the position of ethmoidal and lacrymal accessory nasal sacs. Arrows indicating the entry and exit of water through nasal openings and its course of circulation within the olfactory chamber.
- Fig. 3D. A set of 1-10 lamellae from a rosette of N. nandus.

ANT. NAS. OP.	- Anterior nasal opening
ETH. ACC. NAS. SAC.	- Ethmoidal accessory nasal sac
EY.	- Eye
INTEG.	- Integument
LAC. ACC. NAS. SAC.	- Lacrymal accessory nasal sac
LAM.	- Lamellae
LAM. LESS AREA	- Lamellaeless area
OP. ETH. ACC. NAS. SAC	- Opening of ethmoidal accessory nasal sac
OP. LAC. ACC. NAS. SAC	- Opening of lacrymal accessory nasal sac
POST. NAS. OP.	- Posterior nasal opening
RIM	- Rim

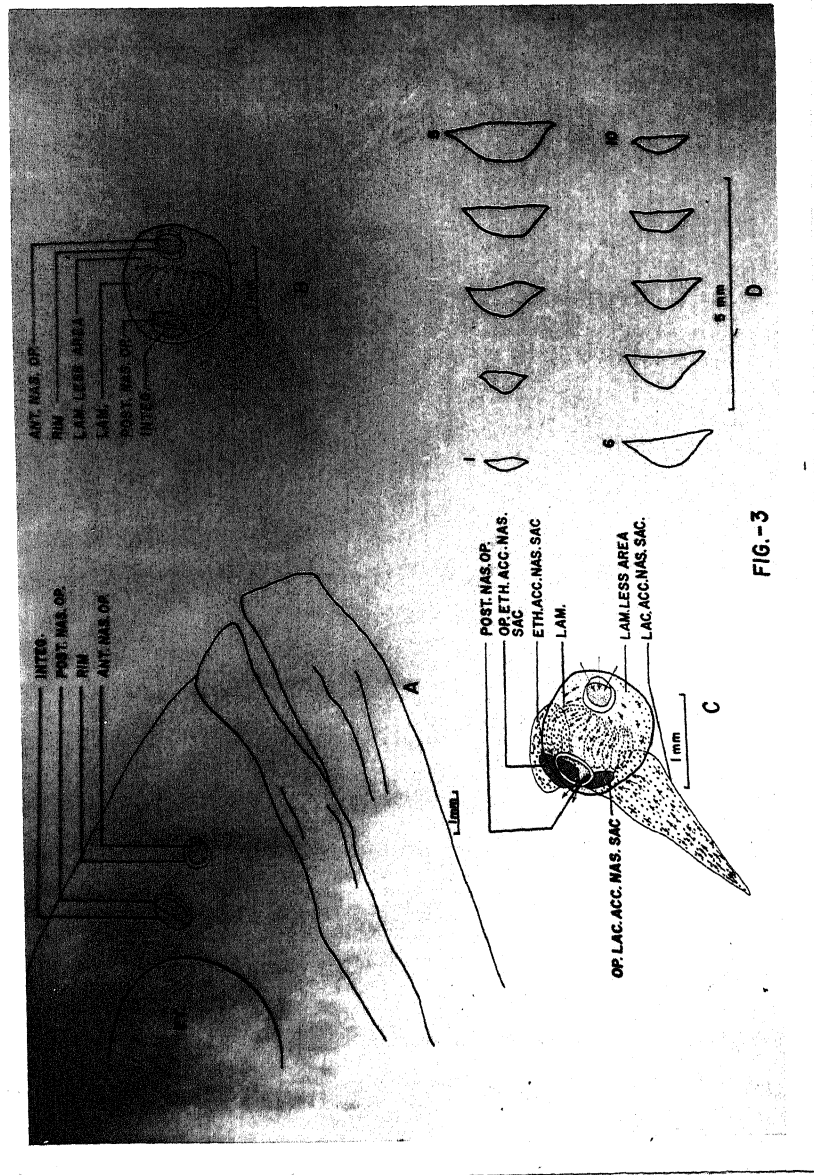


FIG.-3

Fig. 4. Diagram of the lateral view of skull of N. nandus

ASC. PRO. PREMAX.	- Ascending process of premaxilla
DEN.	- Dentary
ENT.	- Entopterygoid
ETH.	- Ethmoid
FRON.	- Frontal
HYO.	- Hyomandibular
INT. OP.	- Interoperculum
LAC.	- Lacrymal
LETH.	- Lateral ethmoid
MAX.	- Maxilla
MPT.	- Metapterygoid
NAS.	- Nasal
OP.	- Operculum
ORBSPH.	- Orbitospheroid
PAL.	- Palatine
PAS.	- Parasphenoid
PREMAX.	- Premaxilla
PRE. OP.	- Preoperculum
PTE.	- Pterygoid
Q.	- Quadrate
SUBOP.	- Suboperculum
SYM.	- Symplactic
2, 3, 4, 5,	- Circumorbitals

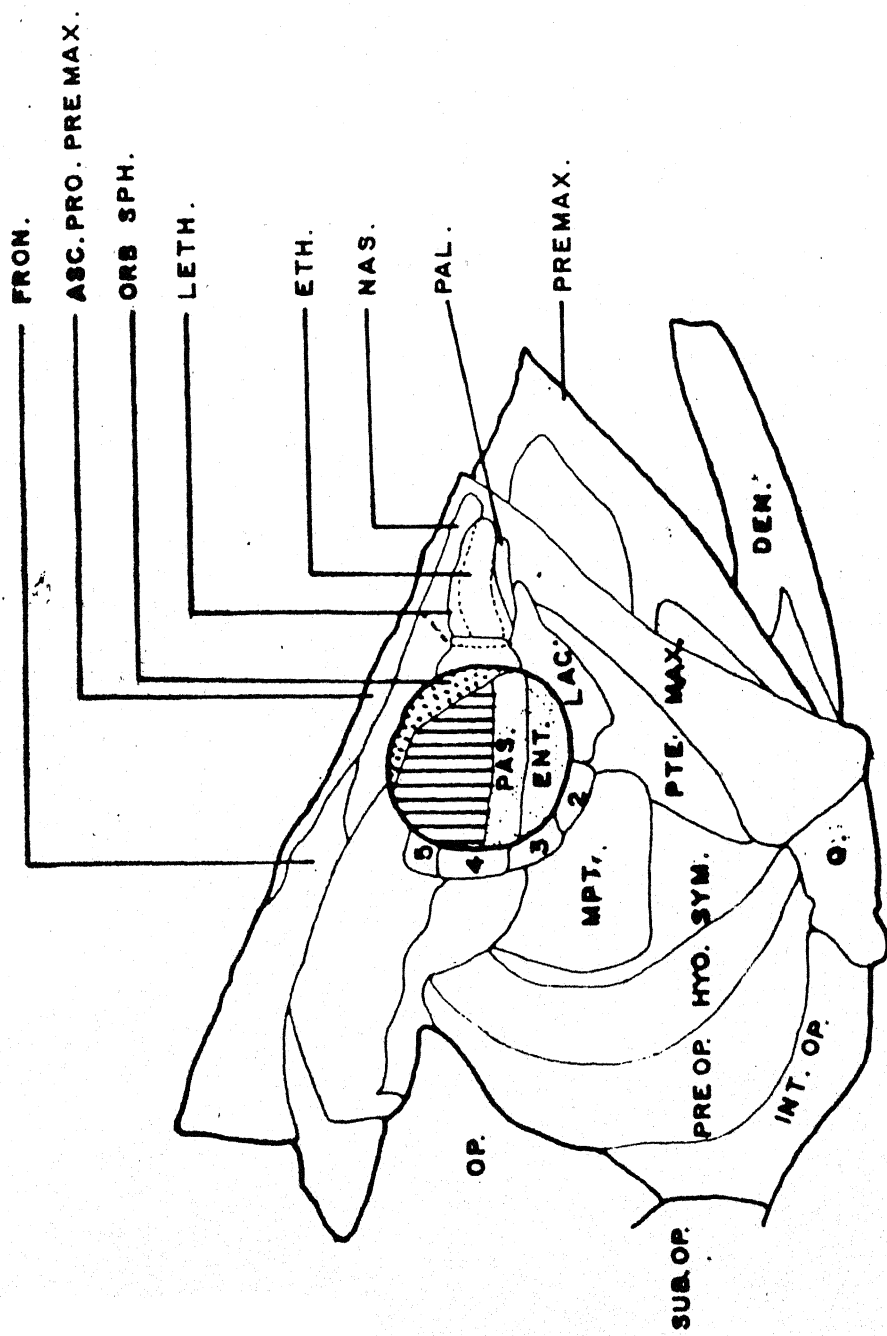


FIG.- 4

Fig. 5. Photograph of the dissection of head of N. nandus from dorsal side to show the relationship of brain with the rosette.

CE.	-	Cerebellum
OLF. BL.	-	Olfactory bulb
OLF. LO.	-	Olfactory lobe
OLF. N.	-	Olfactory nerve
OP. LO.	-	Optic lobe
RE.	-	Rosette

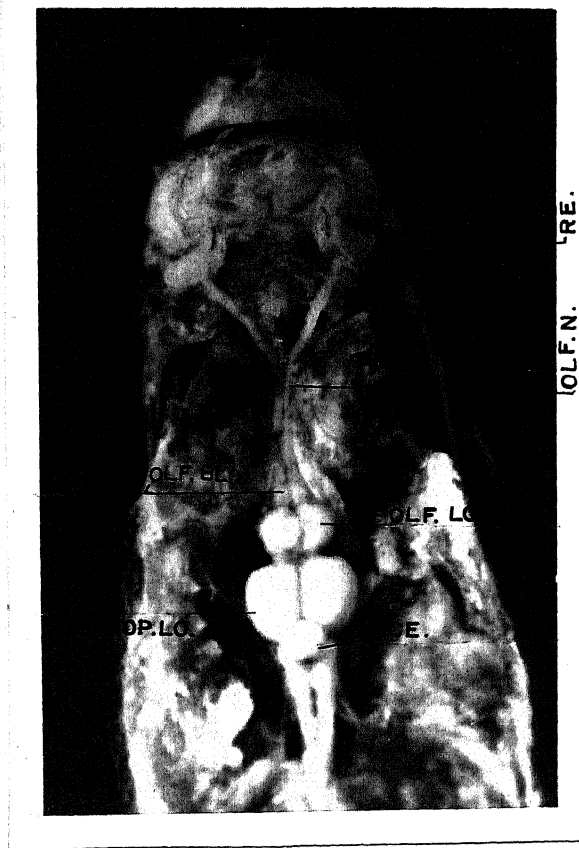


FIG. 5.

MORPHOLOGICAL OBSERVATIONS OF OLFACTORY ORGAN OF  
NANDUS NANDUS (HAMILTON)

The olfactory organs in Nandus nandus are comprised of a pair of olfactory chambers (OLF. CHAM.) lying dorsally on the snout, anterior to and about at the level of the eyes (EY., Figs. 1, 3A). Each olfactory chamber bears a small circular anterior and an oval posterior nasal opening (ANT. NAS. OP., POST. NAS. OP., Figs. 1, 3A, 3B, 3C). The latter is wide and more prominent. The olfactory chamber is somewhat quadrangular in shape, floored with the rosette (RE.) which is having less pronounced olfactory lamellae (LAM., Figs. 2, 3B, 3C). The posterior nasal opening is placed higher as compared to the anterior. The latter is rimmed (RIM.) and nontubular whereas the former having a loose fold of integument (INTEG.), covering half of the opening and acts as a valve (Figs. 3A, 3B). The separate openings of ethmoidal and lacrymal accessory nasal sacs (ETH. ACC. NAS. SAC., LAC. ACC. NAS. SAC., Fig. 3C) are present just below the posterior nasal opening which allow the water circulation in both the sacs through olfactory chamber (Fig. 3C).

In a fish of 142 mm total length, the olfactory chamber is situated 5.50 mm away from the tip of the snout and 1.287 mm from the eye. The anterior and posterior nasal

openings in this specimen lie at a distance of 1.111 mm. The former is 0.468 mm in diameter while the size of the latter is 0.702 mm x 1.170 mm. The size of the olfactory chamber, after removing the integumental formations, is measured 2.925 mm x 2.340 mm.

The area, surrounding the olfactory chamber is provided with numerous chromatophores. It is occupied by a quadrangular olfactory rosette which can easily be visualised after removing the surrounding integument (Figs. 2, 3B, 3C). The olfactory rosette is devoid of raphe and provided with fewer lamellae ranging from 7-10. A smaller area of rosette shows thickening which come out from one point and spread in its major part. The arrangement of lamellae presents a rough appearance of lotus petals, emerging out from one point and expanding at the other. The lamellae (LAM.) in N. nandus are of different type which do not have their separate formations but they are in the form of thickenings, attached with the floor of olfactory chamber. The number of lamellae shows an increasing trend with the growth of the fish. The lingui-form processes are wanting. The lamellae are arranged almost parallel to the body axis (Figs. 2, 3B, 3C).

N. nandus possesses a pair of well developed accessory nasal sacs, associated with each olfactory chamber. The sacs are situated in relation to ethmoid

(ETH.) and lacrymal (LAC.) bones (Fig. 4), consequently, they are named as ethmoidal and lacrymal accessory nasal sacs respectively. The opening of the former (ETH. OP.) is visible in the intact fish through the posterior nasal opening (Fig. 3C). It is oval in shape and in a fish of 142 mm total length its size is 1.170 x 0.819 mm. The lacrymal accessory nasal sac is long and extends to the whole length of lacrymal bone. The wall of the sac is extremely thin and flexible. The opening of lacrymal sac is partly visible through the posterior nasal opening. It is smaller as compared to the opening of ethmoidal sac. The former measures 0.877 x 0.585 mm in a fish of 142 mm total length.

When the mouth is tightly closed, the opening of ethmoidal sac becomes slit like and it remains in its maximum expansion. When it is opened but the premaxilla (PREMAX.) is not extended, this opening remains slit like. However, when the premaxilla is protruded out and its extremely long ascending process (ASC. PRO. PREMAX., Fig.4) is extended rostrally, the opening of the ethmoidal sac becomes stretched and its volume is effected with the elevation of ethmoid. During this protrusion, the lacrymal sac is stretched extremely but narrows in its size causing expulsion of water into the olfactory chamber from both the sacs.

The olfactory chamber is based on palatoethmoid complex and protected from the surrounding by nasal, lateral ethmoid, nasal process of palatine and lacrymal bones. Dorsally the chamber is roofed by slender nasal (NAS.), dorsolaterally by thick skin, posteriorly by lateral ethmoid (LETH.) and ventrally by nasal process of palatine (PAL.), anteroventral part of lateral ethmoid and lacrymal (LAC.) bones (Fig. 4).

Careful removal of the long ascending process of the premaxilla, nasal, frontal (FRON.) and the muscles from the dorsal side, expose the olfactory nerve and the brain. The olfactory bulbs (OLF. BL.) are small and attached to the forebrain. Therefore, they are sessile type. The olfactory lobes are larger and closely attached with the bulbs. Behind the telecephalon lies the mesencephalon (OP. LO.) which mainly consists of large optic lobes (OP. LO., Fig. 5).

#### Ecological coefficient:

The ecological coefficient in N. nandus, measuring from 115 to 176 mm total length, was calculated by two methods: (i) by taking the length of mesencephalon and telencephalon as parameter and (ii) by measuring the areas of two retinae and both the rosettes. By comparing the former with that of latter, the effectiveness of optic and

Table 1: Ecological coefficient of Nandus nandus

l th	Number of lamellae		Total length of brain  (mm)	Length of mesence- phalon  (mm)	Length of telence- phalon  (mm)	Ecological coefficient (Through lobes of brain)  $\frac{\text{Length of telencephalon} \times 100}{\text{Length of mesencephalon}}$	Retinal area of both eyes  (mm <sup>2</sup> )	Olfactory area of both rosette  (mm <sup>2</sup> )	Ecological coefficient (through area)  $\frac{\text{Olfactory area} \times 100}{\text{Retinal area}}$
	Right	Left							
15	7	7	8.775	2.936	2.053	69.925	54.834	39.934	72.827
27	7	8	9.243	3.159	2.094	66.286	58.647	44.237	75.429
33	8	8	9.594	3.217	2.117	65.847	61.524	49.346	80.206
42	8	8	10.620	3.274	2.223	67.898	70.986	55.053	77.554
76	10	9	11.700	3.510	2.340	66.666	90.832	70.113	77.189
			9.986	3.219	2.165	67.324	67.364	51.736	76.641

Table 1: Ecological coefficient of Nandus nandus

Sl. No.	Total length (mm)	Number of lamellae Rosette		Total length of brain (mm)	Length of mesencephalon (mm)	Length of telencephalon (mm)	Ecological coefficient (Through lobes of brain) $\frac{\text{Length of telencephalon} \times 100}{\text{Length of mesencephalon}}$	Retinal area of both eyes (mm <sup>2</sup> )	Olfactory area of both rosette (mm <sup>2</sup> )	Ecological coefficient (through ar Olfactory area x 100 Retinal ar
		Right	Left							
1	115	7	7	8.775	2.936	2.053	69.925	54.834	39.934	72.827
2	127	7	8	9.243	3.159	2.094	66.286	58.647	44.237	75.429
3	133	8	8	9.594	3.217	2.117	65.847	61.524	49.346	80.206
4	142	8	8	10.620	3.274	2.223	67.898	70.986	55.053	77.554
5	176	10	9	11.700	3.510	2.340	66.666	90.832	70.113	77.189
Average				9.986	3.219	2.165	67.324	67.364	51.736	76.641

olfactory faculties can approximately be assessed. The length of mesencephalon and telencephalon varies from 2.936 to 3.510 mm and 2.053 to 2.340 mm respectively, showing the ecological coefficient range from 65.847 to 69.925 per cent (Table 1).

From the area point of view, both the rosette varies from 39.934 to 70.113 mm<sup>2</sup> whereas those of two retinae ranges from 54.834 to 90.832 mm<sup>2</sup>. Ecological coefficient ranges from 72.827 to 80.206 per cent (Table 1). The results thus obtained show that N. nandus is a microsmatic fish because it possesses tremendously developed optic faculty as compared to that of olfactory which is very much regressed. This suits to its highly predaceous habit, preying on fishes half of its size. In this action N. nandus visually target the fish and capture the same as its prey.

The route of water circulation through the olfactory chamber of N. nandus:

The fish exhibits a characteristic of continuous protruding and retracting its jaw apparatus during normal swimming and feeding conditions. The above action, in addition to forward movement of fish, causes the entry of water through anterior nasal opening. The water circulates in the olfactory chamber freely as its major part is lamellaeless and whatever the lamellae present, are the simple thickenings of the floor of olfactory chamber

(Figs. 3B, 3C). It is connected with the ethmoidal and lacrymal accessory nasal sacs (ETH. ACC. NAS. SAC., LAC. ACC. NAS. SAC.) by well defined openings. Immediately after reaching into the olfactory chamber through anterior nasal opening, water takes its route to both the accessory nasal sacs through their separate openings. When the mouth is closed, jaws are retracted causing the reduction in the volume of accessory nasal sacs and olfactory chamber (Fig. 3C). This leads to the expulsion of water from posterior nasal opening. The valved condition of posterior nasal opening demonstrates unidirectional flow of water from anterior to posterior nasal opening (Figs. 3A, 3B, 3C).



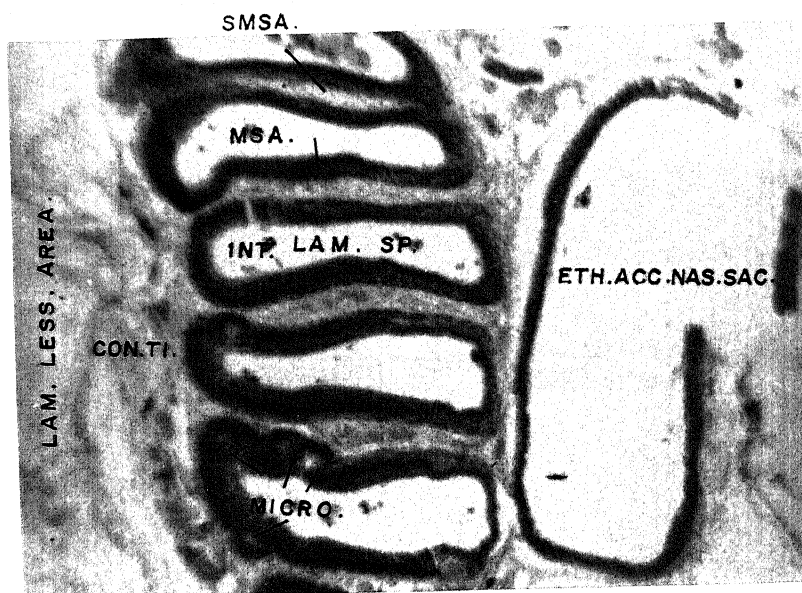


FIG. 6.

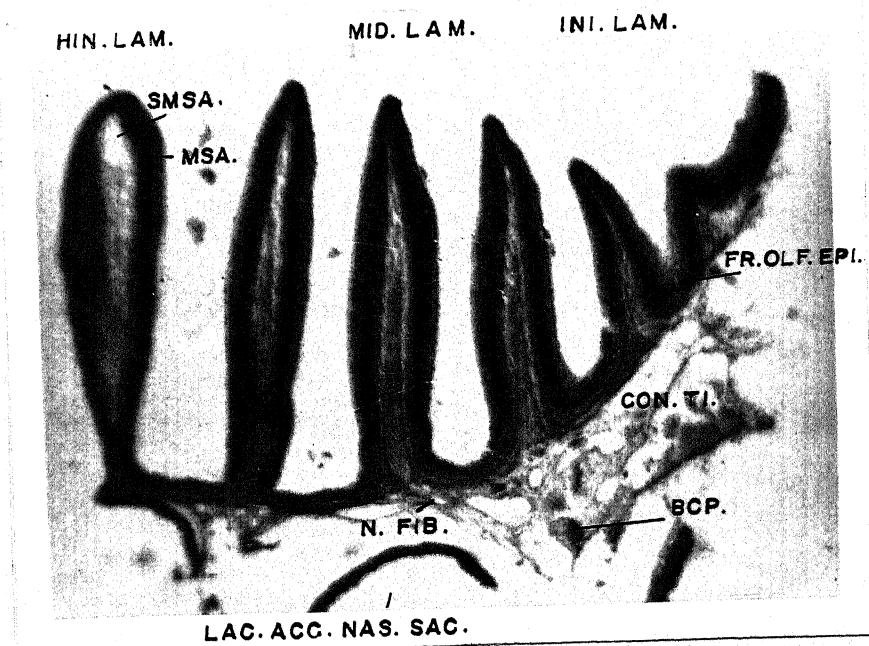


FIG. 7.

Fig. 6. Horizontal section of the rosette of N. nandus showing parallel arrangement of lamellae with ethmoidal accessory nasal sac. Magnification x 50.

Fig. 7. Transverse section of the rosette of N. nandus showing differentiation of the lamellae as initial, middle and hinder ones. Lacrymal accessory nasal sac associated with rosette is visible. Magnification X 50

BCP.	- Blood capillary
CON. TI.	- Connective tissue
ETH. ACC. NAS.SAC	- Ethmoidal accessory nasal sac
FR. OLF. EPI.	- Floor of olfactory epithelium
HIN. LAM.	- Hinder lamellae
INI. LAM.	- Initial lamellae
INT. LAM. SP.	- Interlamellar space
LAC. ACC. NAS.SAC	- Lacrymal accessory nasal sac
LAM. LESS AREA	- Lamellaeless area
MICRO.	- Microformations
MID. LAM.	- Middle lamellae
MSA.	- Mucosa
N. FIB.	- Nerve fibre
SMSA.	- Submucosa

Fig. 8. Transverse section of the rosette of N. nandus passing through a set of initial and middle lamellae. Microformation in the form of vacuole is visible in the middle one. Magnification X 50.

Fig. 9. Transverse section of the rosette of N. nandus passing through a set of middle lamellae with an outgrowth of minor lamella from the floor of olfactory epithelium in the interlamellar space. Magnification X 100.

BCP.	- Blood capillary
BC. Z.	- Basal zone
BM.	- Basement membrane
CON. TI.	- Connective tissue
DE. LAM.	- Distal end of lamella
FR. OLF. EPI.	- Floor of olfactory epithelium
GR. BC.	- Grouping of basal cells
INT. LAM. SP.	- Interlamellar space
MICRO.	- Microformations
MIN. LAM.	- Minor lamella
MN. FIB.	- Medullated nerve fibre
MSA.	- Mucosa
PRO. LAM.	- Proximal end of lamella
SC. Z.	- Supporting zone
SMSA.	- Submucosa

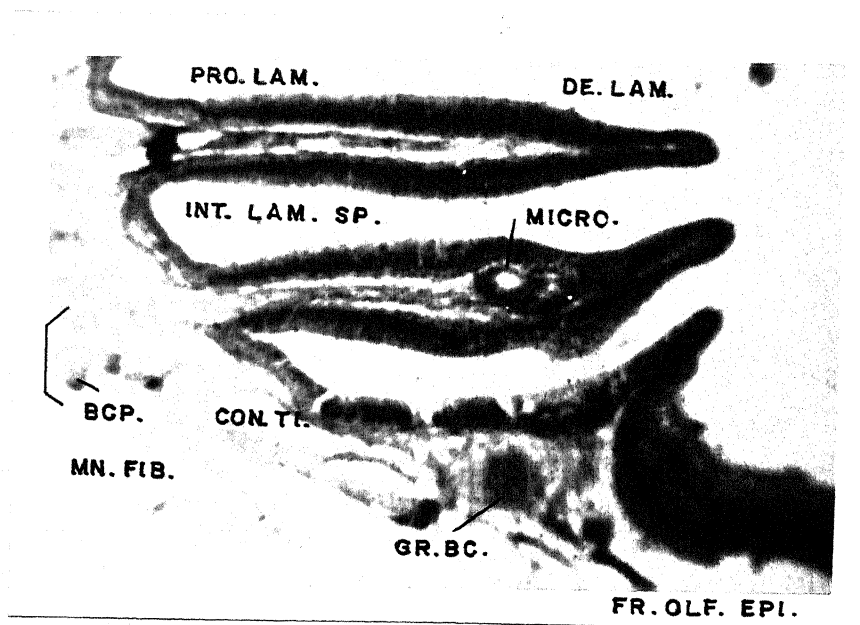


FIG. 8.

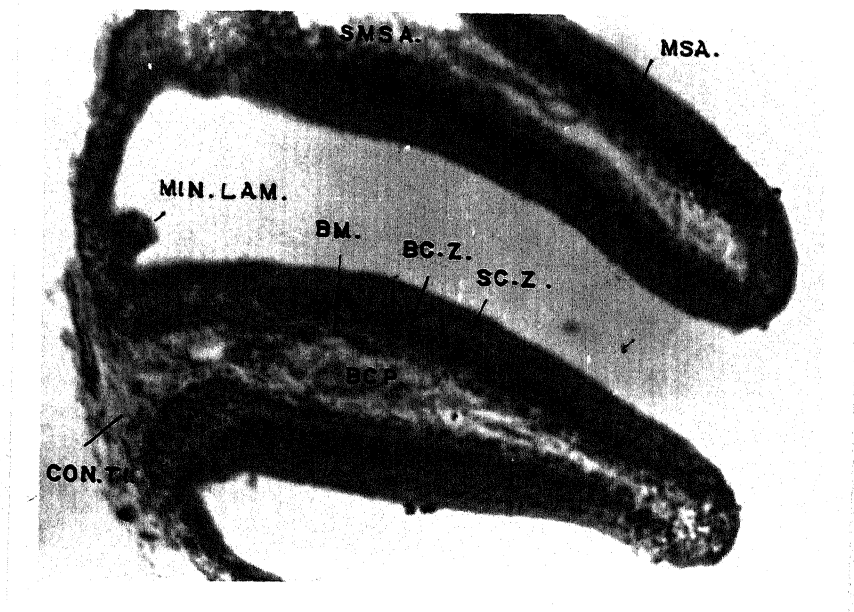


FIG. 9.



Fig. 10. Transverse section of the rosette of N. nandus passing through a set of hinder lamellae, exhibiting enormous enlargement of submucosa with scattered connective tissue and spacious areolae. Magnification X 100.

Fig. 11. Transverse section of the initial lamella of N. nandus showing rod shaped receptor cells with their dendrites are marked with dots, arrows and simple line. Magnification X 400.

ARE.	-	Areolae
BC.	-	Basal cells
BCP.	-	Blood capillary
BC. Z.	-	Basal zone
BM.	-	Basement membrane
CI.	-	Cilia
CI. SC.	-	Ciliated supporting cell
CON. TI.	-	Connective tissue
DE. LAM.	-	Distal end of lamella
FBC.	-	Fibroblast
FI. OLF.	-	Folium olfactorium
GC.	-	Goblet cell
GC. TH.	-	Theca of goblet cell
HIS.	-	Histiocyte
MSA.	-	Mucosa
OCI.	-	Olfactory cilia
PRO. LAM.	-	Proximal end of lamella
RR.	-	Rod shaped receptor cell
SMSA.	-	Submucosa

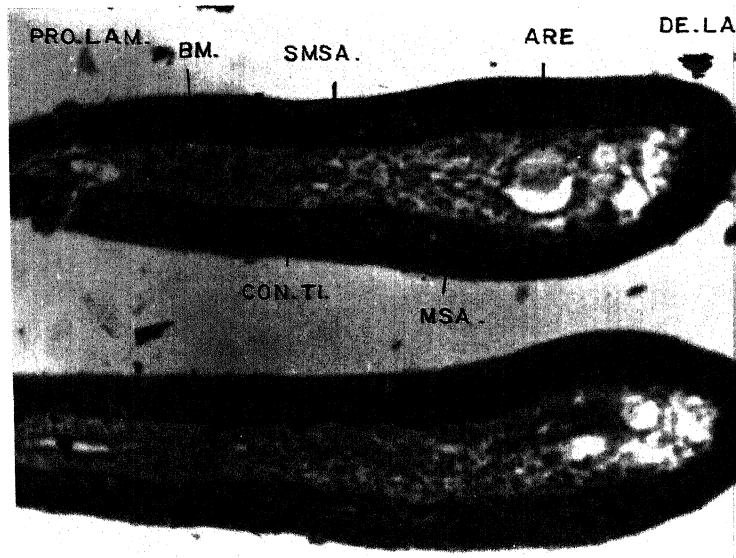


FIG. 10.

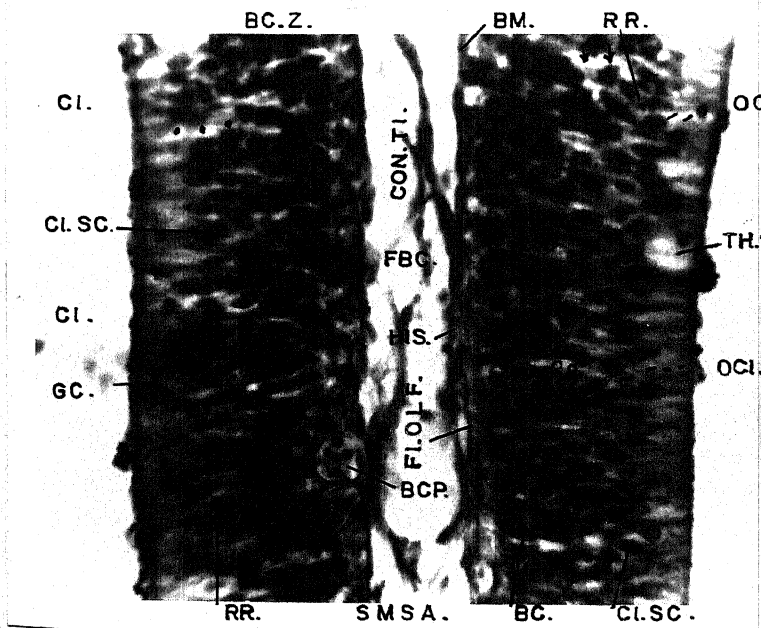


FIG. 11.



HISTOLOGICAL OBSERVATIONS OF OLFACTORY ORGAN OF  
NANDUS NANDUS (HAMILTON)

The olfactory rosette (RE.) of Nandus nandus is quadrangular in shape which bears lamellae (LAM.) in the form of thickenings, coming out from the olfactory epithelium (OLF. EPI.). The rosette is devoid of raphe and its endings are free from the lamellar thickenings. The arrangement of olfactory lamellae in the central part of the rosette gives a rough impression of petals of lotus (Figs. 2, 3B, 3C, 6). All the lamellae are attached with the floor of olfactory epithelium with their ventral and remain projected in the olfactory chamber through their dorsal surfaces. The lamellae are separated from each other by well defined interlamellar spaces (INT. LAM. SP.) whereas their distal (DE. LAM.) and proximal ends (PRO. LAM.) remain attached with the rosette (Fig. 6). The lamellae are constituted of central core or submucosa (SMSA.), lined on both the sides by cellular components of mucosa (MSA.). The mucosa is mainly constituted of ciliated columnar epithelium and abundantly supplied with basal cells (BC.). The basement membrane (BM.) stands as partition in between submucosa and mucosa (Figs. 6, 7, 8, 11, 12, 21, 22). The mucosal zone exhibits great variation in its thickening in all the lamellae and possess some peculiar microformations (MICRO.) which are due to the flow of basal cells in different patterns (Figs. 8, 12, 15, 16, 25).



This flow (Figs. 18, 19, 20) causes the displacement of other cellular components and subsequently leads in the formation of cuneiform (CUN.), filiform (FIL.) and fungiform (FUNG.) mucosal surface which is supposed to increase the olfactory area. With the result of these formations, there appears depressions (DPR.) and elevations (ELE.) of different sizes which may take the shape of flask (FL.), funnel (FN.), vacuole (VAC.), minor and hillock elevations (MIN. ELE., HIL., ELE., Figs. 19, 20, 25, 26, 27, 28, 29, 30, 31, 32).

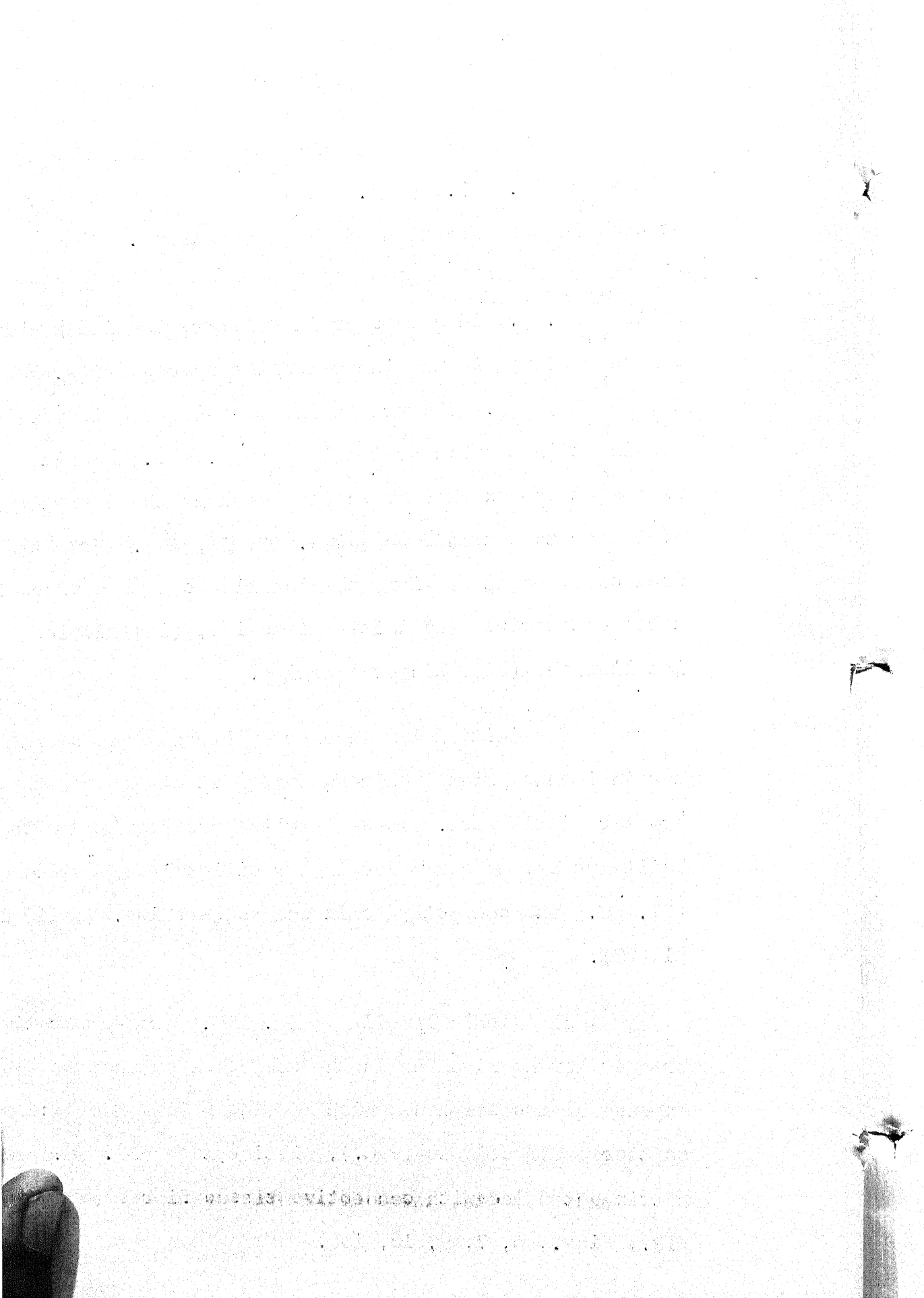
The grouping of basal cells (GR. BC., Figs. 8, 12, 14, 20, 25, 30) and their migration (Figs. 18, 19, 20, 32) in different patterns in the surface of lamella cause the formation of 'olfactory buds' (OLF. BUD) of different shapes, sunken in the lamellar surface (Figs. 25, 27, 28, 29, 30, 31, 32). Such formations are richly supplied with receptor cells, projecting their dendrites towards the interlamellar spaces which may further bear cilia. The minor lamellae are (MIN. LAM., Figs. 9, 13, 14) also observed but they are present in the interlamellar spaces of middle lamellae, formed of only mucosal cellular components. The microformations are richly visible in the middle and hinder lamellae whereas initial ones do not exhibit such feature. It is commonly observed that the lamellae are subjected to the activity of basal cells which may push the mucosa in the form of a bulging (Figs. 18, 19,



20) at any place and giving the shape of transtionary epithelium (T. EPI., Figs. 16, 18, 23, 26) which may proceed in the direction of microformations. The olfactory epithelium also discharges or extrudes its cells (EXT. C.) in groups or in solitary condition which can be observed in the interlamellar spaces (Figs. 18, 20, 24, 25, 26, 28). The broadening of submucosa is very prominent in the hinder lamellae (HIN. LAM.) and it widens at the expense of mucosa, causing the reduction of latter to a thin zone (Figs. 10, 15, 16). From the submucosal point of view, the lamellae can be divided into three categories: (i) initial lamellae, (ii) middle lamellae and (iii) hinder lamellae.

The initial lamellae are well composed having their terminal ends pointed whereas narrow at the base with their broader middle part. These lamellae are provided with well built mucosa, made up of columnar ciliated supporting cells (CI. SC.) and compactly built submucosa (Figs. 7, 11, 12, 21, 22).

The middle lamellae (MID. LAM.) are comparatively broader having widening in the submucosa but not at the expense of mucosal zone which remains well formed and shows scattered fibroblasts (FBC.), histiocytes (HIS.) and dense matrix entangled with connective tissue fibres (CON. TI. FIB., Figs., 6, 7, 9, 13, 18).



The hinder lamellae (HIN. LAM.) are provided with enormously developed submucosa which causes the reduction in the thickening of mucosal zone. With the result of widening of submucosa, areolae (ARE.) appear due to the rare distribution of connective tissue fibres and other cells in this zone. The basement membrane is pushed to the periphery. These are old and worn out lamellae which have attained full size (Figs. 6, 7, 10, 15, 16).

The cellular components in N. nandus may be identified as supporting cells (SC.), receptor cells (RC.) goblet cells (GC.) and basal cells (BC.). The submucosa is supplied with connective tissue fibres, fibroblasts (FBC.), histiocytes (HIS.) basal (BC.) and pigment cells (PIG.).

#### The supporting cells:

The supporting cells of N. nandus are subjected to great variation because of the enormous production of basal cells and their subsequent migration in different patterns showing changes in mucosal region.

The supporting cells are ciliated (CI. SC.) and present in well composed initial lamellae. In the middle and proximal parts, these cells are having elongated body with oval nucleus (NU. CI. SC.) which bears one or two nucleolus. The chromatin material is visible and distri-



buted in karyoplasm. The outer or distal limbs (DE. CI. SC.) are elongated, extending upto the peripheral surface of the lamellae which bear cilia (CI.). The cilia of supporting cells are considerably long, projected in interlamellar spaces and showing a trend of directional movement, depending upon the pressure of water, coming out from both the accessory nasal sacs. The outer or distal limb of the supporting cell contains homogenous and eosinophilic cytoplasm. The inner or proximal limb is inconspicuous and difficult to trace among the other cellular components, lying beneath these cells (Figs. 11, 12, 21, 22).

With the result of great variation in mucosal surface, the supporting cells are affected and exhibit variation in their shape and occurrence. The mucosa may be affected either by enormous broadening of submucosal zone or by the movement of basal cells. In the former case, the supporting cell becomes oval and short with almost oval nucleus and invisible chromatin material. These cells become inconspicuously ciliated and bear short outer or distal limb (Figs. 13, 14, 15, 16). In the zone of microformations where tremendous migration of basal cells is observed, the supporting cells cannot be clearly identified from migratory basal cells and receptor cells (Figs. 20, 25, 27, 28, 29, 30, 31, 32). Such zones which may be either in the form of elevations or depressions, the

Fig. 12. Transverse section of the initial lamella of N. nandus showing the presence of rod shaped receptor cells and olfactory cilia. Connective tissue is well defined in the submucosa. Dendrites of rod shaped receptor cells are marked by arrow heads. Magnification X 400.

Fig. 13. Longitudinal section of the middle lamella of N. nandus passing through the minor one, exhibiting thick concentration of basal cells. Magnification X 400.

BC.	- Basal cell
BC. Z.	- Basal zone
BM.	- Basement membrane
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
DE. CI. SC.	- Distal end of ciliated supporting cell
FBC.	- Fibroblast cell
FI. OLF.	- Folium olfactorium
GC.	- Goblet cell
GR. BC.	- Grouping of basal cells
INT. LAM. SP.	- Interlamellar space
MIN. LAM.	- Minor lamella
OCI.	- Olfactory cilia
RR.	- Rod shaped receptor cell
SC.	- Supporting cell
SC. Z.	- Supporting zone

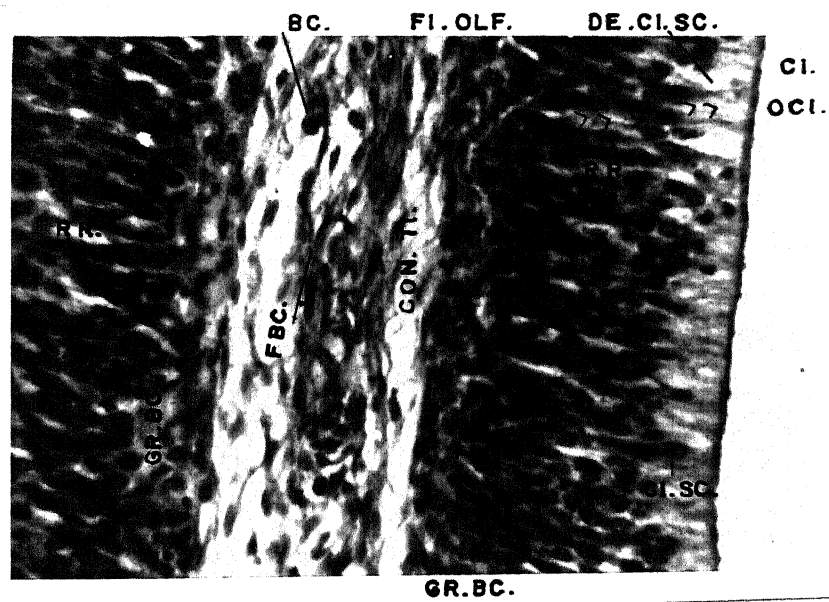


FIG. 12.

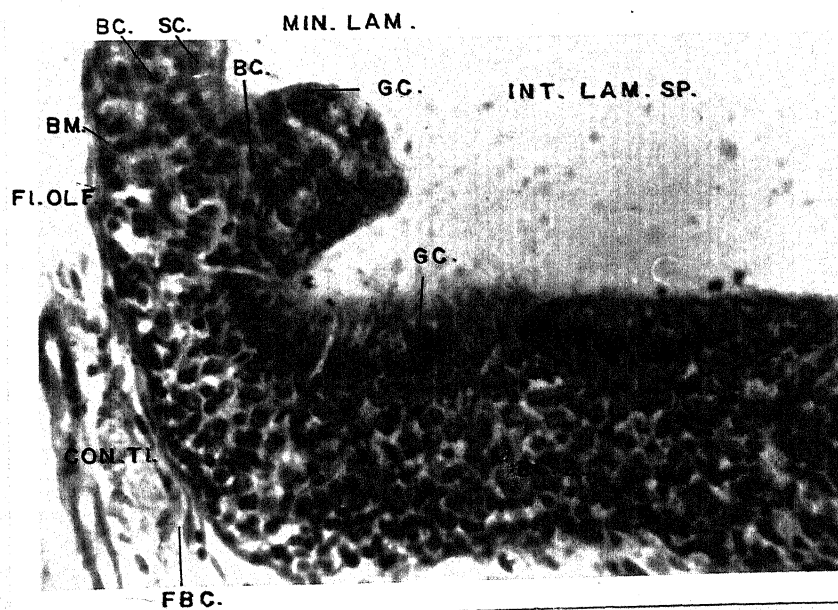


FIG. 13.

14. Longitudinal section of the middle lamella of N. nandus exhibiting the composition of mucosa and submucosa with specific markings on receptor and goblet cells. Magnification X 400.
15. Transverse section of the hinder lamella of N. nandus, showing enormous enlargement of submucosa at the expense of mucosa with blood capillary, areolae and connective tissue. Magnification X 400.

ARE.	- Areolae
BC.	- Basal cell
BCP.	- Blood capillary
BM.	- Basement membrane
CON. TI. FIB.	- Connective tissue fibres
CI. SC.	- Ciliated supporting cell
FBC.	- Fibroblast cell
GC.	- Goblet cell
GR. BC.	- Grouping of basal cells
HIS.	- Histocyte
INT. LAM. SP.	- Interlamellar space
MSA.	- Mucosa
PN.	- Primary neurone
SC.	- Supporting cell
SMSA.	- Submucosa
SR.	- Spindle shaped receptor cell

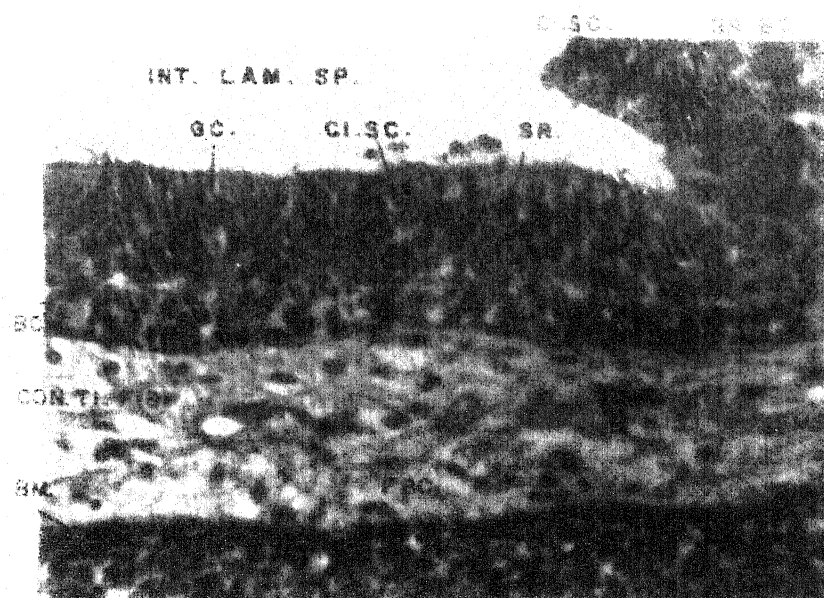


FIG. 14.

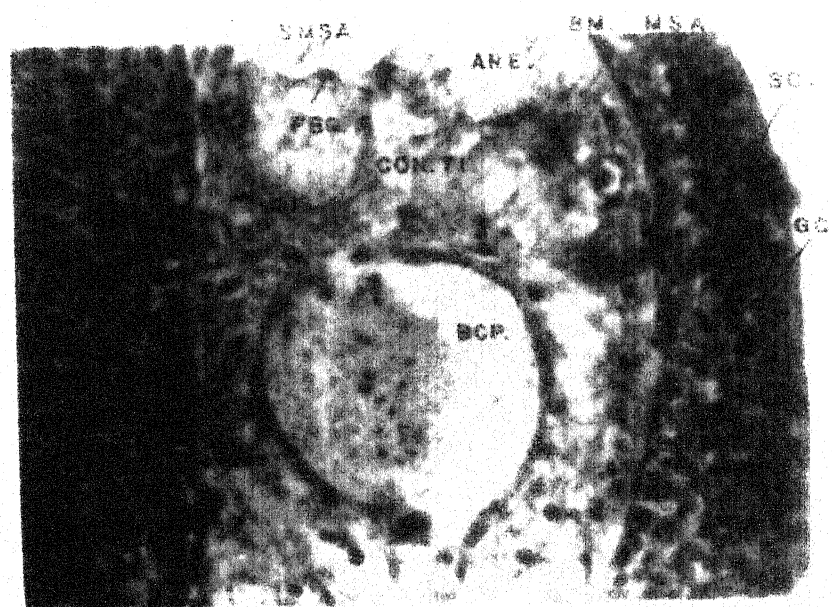


FIG. 15.

Longitudinal section of the middle lamella of N. nandus exhibiting the composition of mucosa and submucosa with specific markings on receptor and goblet cells. Magnification X 400.

Transverse section of the hinder lamella of N. nandus, showing enormous enlargement of submucosa at the expense of mucosa with blood capillary, areolae and connective tissue. Magnification X 400.

ARE.	- Areolae
BC.	- Basal cell
BCP.	- Blood capillary
BM.	- Basement membrane
CON. TI. FIB.	- Connective tissue fibres
CI. SC.	- Ciliated supporting cell
FBC.	- Fibroblast cell
GC.	- Goblet cell
GR. BC.	- Grouping of basal cells
HIS.	- Histiocyte
INT. LAM. SP.	- Interlamellar space
MSA.	- Mucosa
PN.	- Primary neurone
SC.	- Supporting cell
SMSA.	- Submucosa
SR.	- Spindle shaped receptor cell

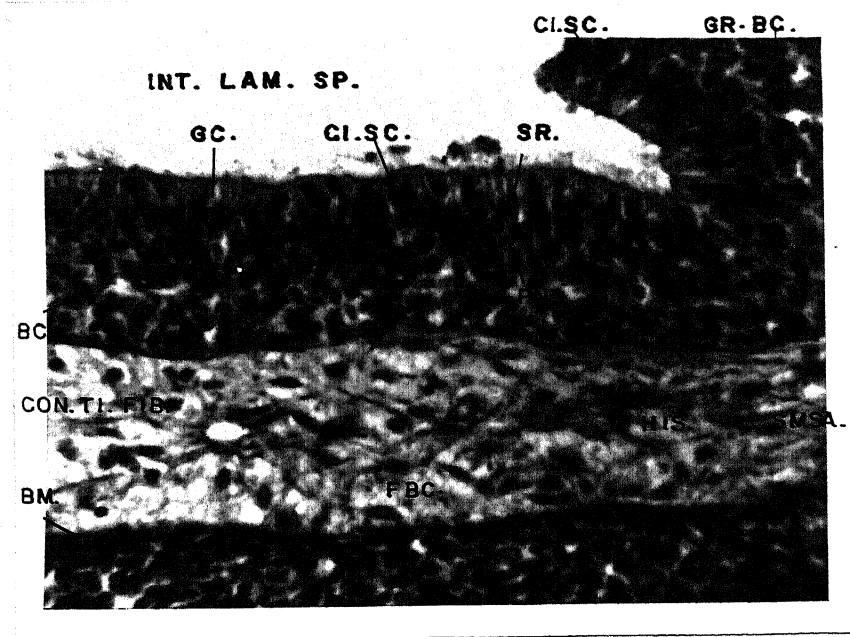


FIG. 14.

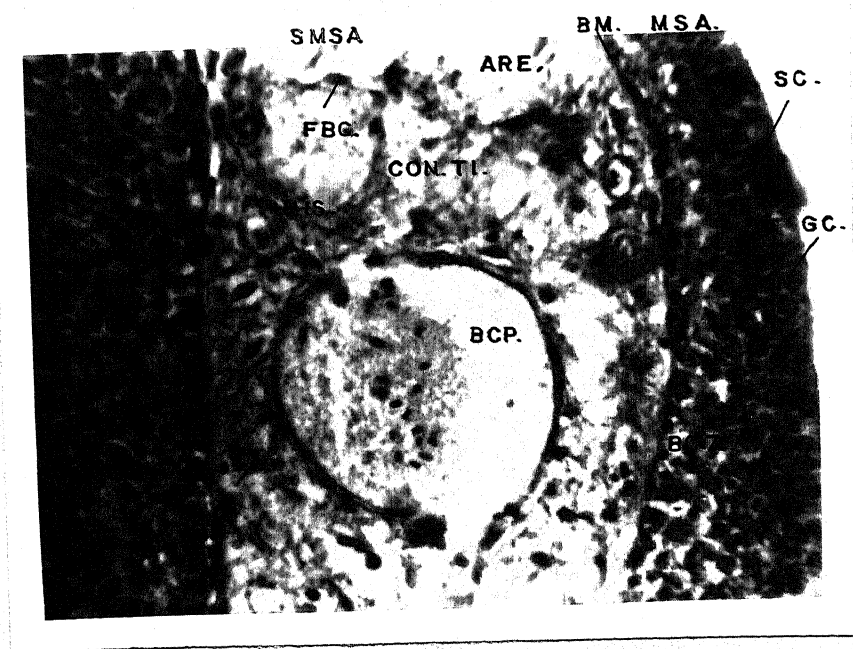


FIG. 15.

Fig. 16. Transverse section of the hinder lamella of N. nandus showing excessive enlargement of submucosa with scattered connective tissue. Mucosa is reduced to a thin layer, revealing the presence primary neurones, goblet and supporting cells. Magnification X 400.

Fig. 17. Transverse section of the rosette of N. nandus passing through the emergence of lamellae, demonstrating the blood sinus, connective tissue and branched pigment cells. Magnification X 400.

BC.	- Basal cell
BC. Z.	- Basal zone
BL. SI.	- Blood sinus
BM.	- Basement membrane
CON. TI.	- Connective tissue
DPR.	- Depression
ELE.	- Elevation
FBC.	- Fibroblast cell
GC.	- Goblet cell
HIS.	- Histiocyte
INT. LAM. SP.	- Interlamellar space
MN. FIB.	- Medullated nerve fibre
MSA.	- Mucosa
NMN. FIB.	- Nonmedullated nerve fibre
PIG.	- Pigment cell
PN.	- Primary neurone
SC.	- Supporting cell
SMSA.	- Submucosa

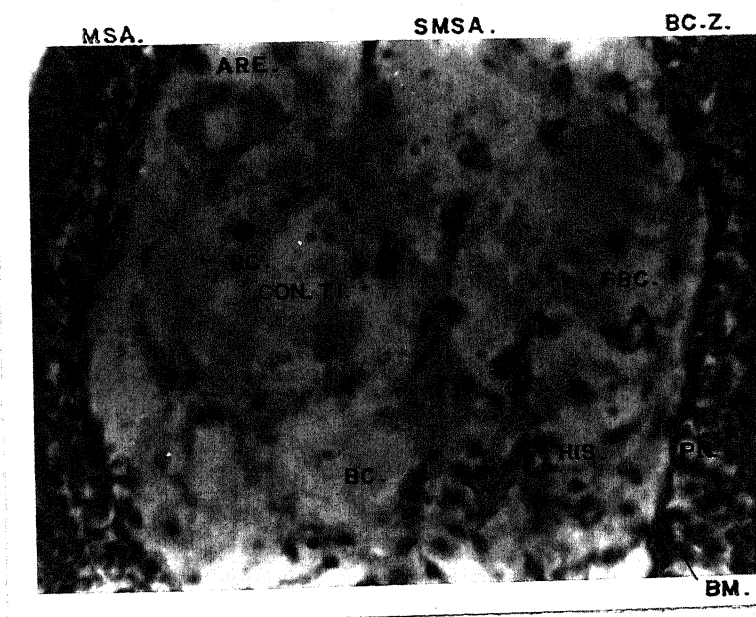


FIG. 16.

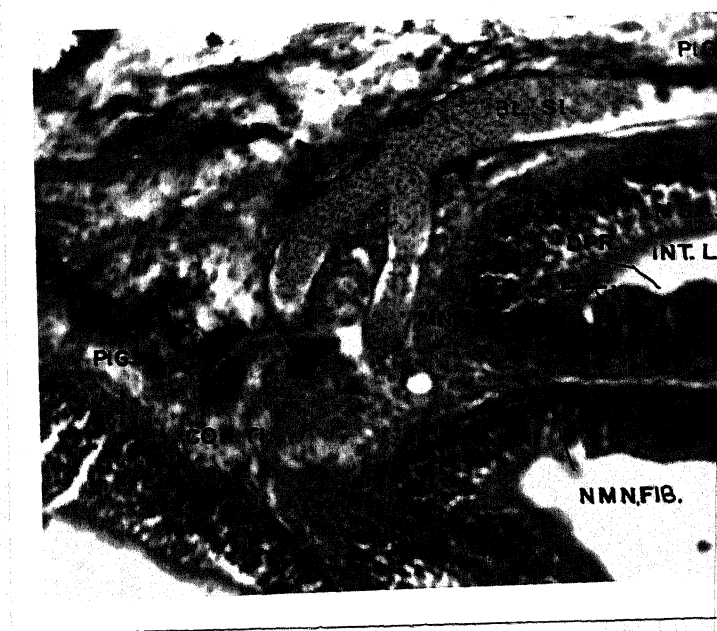


FIG. 17.

Fig. 18. Transverse section of the middle lamella of N. nandus demonstrating transitional epithelium and submucosa wherein basal cells are seen migrating to give rise microformations of different pattern. Magnification X 400.

Fig. 19. Transverse section of the lamella of N. nandus where basal cells are accumulated, pushing the mucosa in the form of a dom shaped elevation. The elevation is alternated on either sides by depressions. Enormously enlarged submucosa with scattered connective tissue is also visible. Magnification X 400.

ARE.	- Areolae
BC.	- Basal cell
BC. Z.	- Basal zone
BM.	- Basement membrane
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
DPR.	- Depression
ELE.	- Elevation
EXT.C.	- Extrusion of cell
FBC.	- Fibroblast cell
GC.	- Goblet cell
GR. BC.	- Grouping of basal cell
HIS.	- Histiocyte
MSA.	- Mucosa
SC.	- Supporting cell
SMSA.	- Submucosa
T. EPI.	- Transitional epithelium

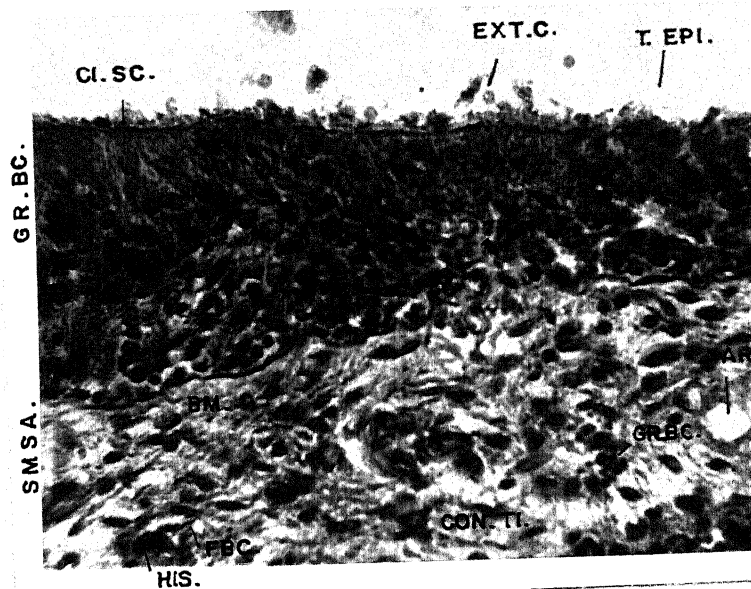


FIG. 18

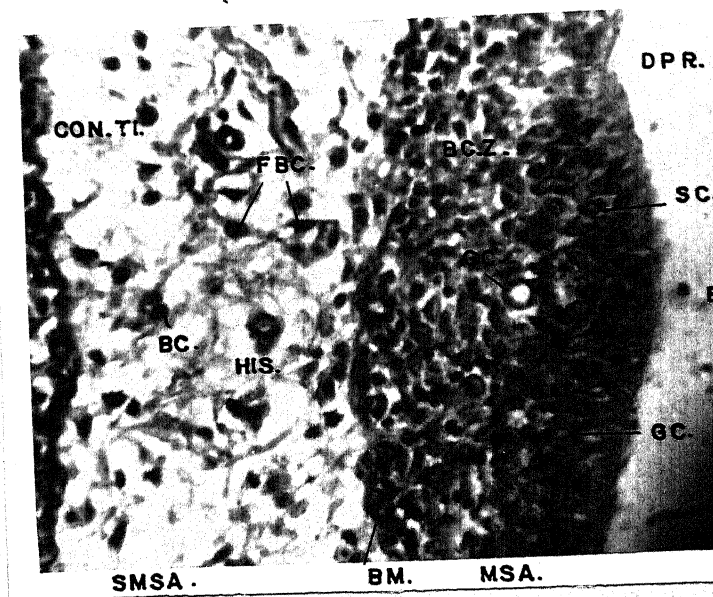


FIG. 19.



supporting cells are of the size of basal cells or may be in the formative stage, leading to microformations of different patterns. The indifferent epithelium (Figs. 18, 19, 20, 25), where basal cells migrate in different patterns, is supposed as the transitional phase and receptor cells can only be identified because of clear dendrites and axons, extending in their respective direction in the mucosal zone (Figs. 23, 24, 28, 29, 32).

The receptor cells:

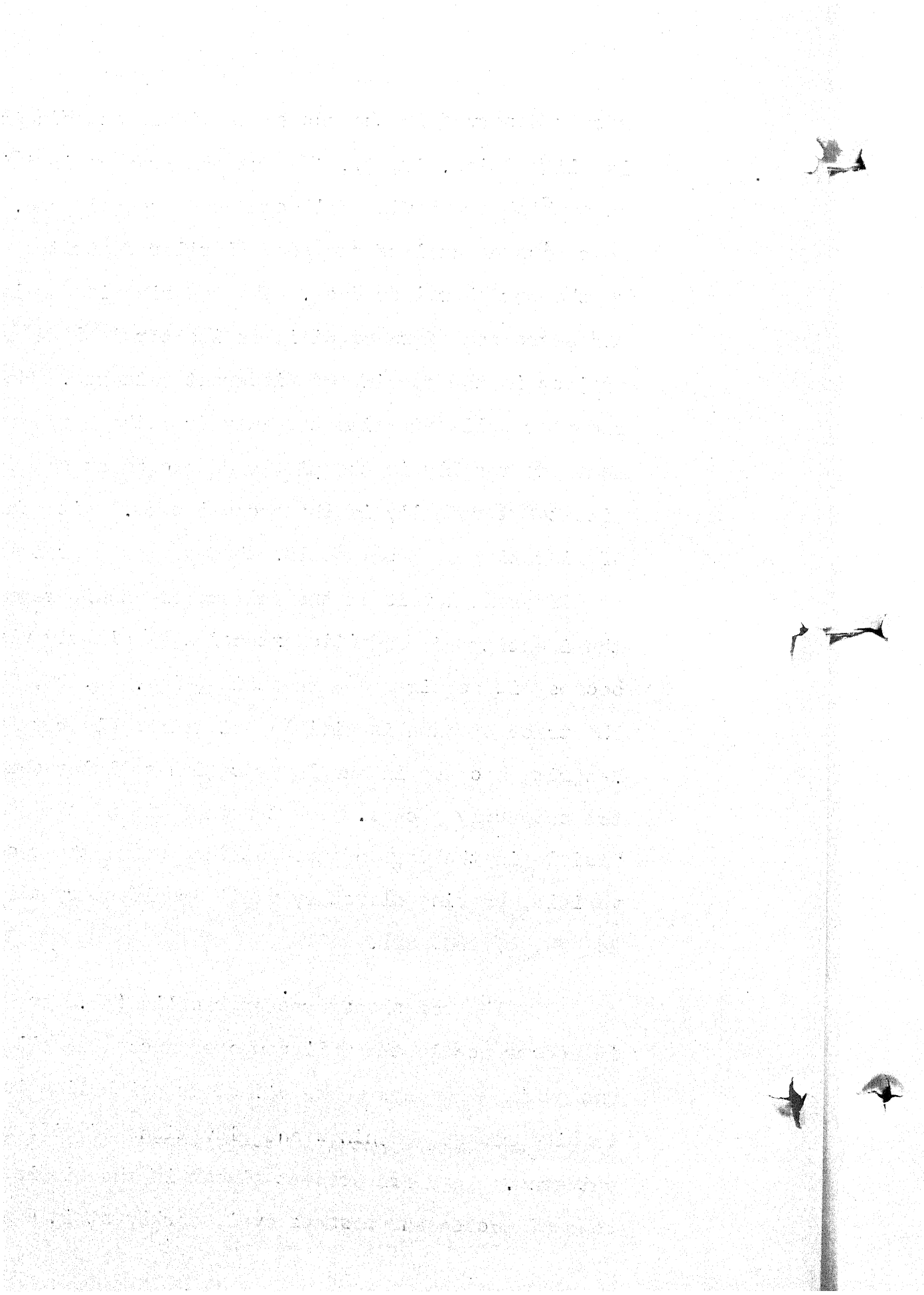
The receptor cells are observed throughout the epithelium of N. nandus irrespective of their restriction in any particular region of the lamella. But however, they are concentrated in the mucosal deepenings in the form of flask, funnel, vacuole and tubule which are called olfactory crypts (CRY.) formed for the purpose of increasing the olfactory surface. Such deepenings are alternated by elevations in the shape of cuneiform, filiform, fungiform, minor and hillock elevations which are supposed as purely supporting zones and devoid of receptor concentration (Figs. 24, 26, 27, 28, 29, 30, 31, 32). The receptor cells in N. nandus can be identified as primary neurones (PN., Figs. 24, 26, 28, 29, 30, 32), spindle (SR. Figs. 14, 23, 24) and rod shaped receptors (RR., Figs. 11, 12, 21, 22).

The primary neurones (PN.) are confined in the crypts of different patterns (Figs. 24, 26, 27, 28, 32) and



rarely observed in the mucosa of middle and hinder lamellae (Figs. 13, 14, 16) but not present in initial ones which are having well composed mucosal zone. They bear rounded nucleus and send fibrillar dendrites (DN. PN.) to the peripheral surface. The dendrite is darkly stained and bears some form of cilia on its terminal end which project in the opening of different patterns. These receptor cells are situated away from the basement membrane roughly in the middle of mucosa or sometimes situated terminally in the mucosal zone. With the result of migration of basal cells, the primary neurones are pushed at different levels in the uniform or ununiform mucosa but the identity of dendritic extension is clearly visible because it acquires a dark stain (Figs. 24, 28, 29, 32). The trace of axon is visible but not as clearly as that of dendrite because in the lower region cellular components are compactly packed. The terminal tip of the dendrite is visible in the form of dark stained spot, the receptor vesicle, bearing olfactory villi or olfactory cilia (Figs. 24, 28, 29, 30, 32).

The rod shaped receptor cells (RR.) are common in occurrence in the well composed mucosa of all the lamellae except in the zones where olfactory epithelium is activated to give rise to deepenings and elevations of different patterns. They are present almost in the middle lower zone of mucosa and possess oval, darkly stained nucleus



with conspicuous dendritic extensions (DN. RR.) towards the interlamellar spaces. The terminal tips of dendrites bear some form of cilia, projected in the interlamellar spaces. These receptor cells bear darkly stained nuclei. The axonal extension (AX. RR.) of these rod shaped receptor cells can be clearly traced out. These receptors are present almost at the level below the zone of supporting cells, thereby having less elongated axons which sometimes give the appearance as the rod shaped receptors are directly coming out from folium olfactorium (FI. OLF., Figs. 11, 12, 21, 22).

The spindle shaped receptor cells (SR.) are rare in occurrence in the mucosa of N. nandus, however, present in the zones of transitional mucosa or sometimes in the thin mucosa of hinder and middle lamellae (Figs. 14, 23, 24). They are not observed in the initial lamellae where mucosa is well composed. They are shorter as compared to rod shaped receptor cells but larger than the primary neurones. They may be seen at any level of mucosa, having somewhat oval nucleus with clearly visible chromatin material. They can be rarely observed in different patterns of deepenings among primary neurones and migratory basal cells (Fig. 24).

The primary neurones (PN.) are present in the olfactory crypts (CRY.) in large number with their dendrites projected in the lumen of different forms of deepenings,

taking the shape of olfactory bud which can be commonly observed in the lamellae of N. nandus (Figs. 24, 25, 26, 27, 28, 29, 32). The rod and spindle shaped receptor cells are distributed in the mucosa in a solitary manner among the supporting cells. Such ununiform accumulation of receptor cells gives an impression that different patterns of deepenings are the major spots of olfactory reception whereas the general surface responds for olfactory reception occasionally.

The synaptic contact between any two receptor cells has not been observed anywhere in the olfactory epithelium of N. nandus and independent identity of each type of receptor cell is maintained in both solitary and aggregatory arrangement. The axons of all the receptor cells extend proximally and join folium olfactorium (FI. OLF., Figs. 21, 23) along the basement membrane.

The goblet cells:

The goblet cells (GC.) are rare in occurrence and occasionally observed in different zones of mucosal layer. They can be rarely seen at any level of mucosa (Figs. 11, 13, 14, 16, 19) and originate from the basal zone due to muciferous activity of basal cells. The mucous cells are richly supplied in the epithelium of accessory nasal sacs (Figs. 33, 34, 35). Because of the rare occurrence of goblet cells, very little muciferous

Fig. 20. Transverse section of the lamella of N. nandus, showing irregular mucosal surface with depressions, hillock elevations and extruded cells in the interlamellar space. Magnification X 400.

Fig. 21. Transverse section of the initial lamella of N. nandus, showing its cellular components in high magnification. Nucleus, dendrite and axon of rod shaped receptor cells with ciliated supporting cells are demonstrated in the section. Arrows indicating the pathways of dendrites. Magnification X 1000.

AX. RR.	- Axon of rod shaped receptor cell
BCP.	- Blood capillary
BC. Z.	- Basal zone
BM.	- Basement membrane
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
DE. SC.	- Distal end of supporting cell
DN. RR.	- Dendrite of rod shaped receptor cell
DPR.	- Depression
EXT. C.	- Extrusion of cells
FI. OLF.	- Folium olfactorium
GC.	- Goblet cell
GR. BC.	- Grouping of basal cells
HIL. ELE.	- Hillock elevation
MSA.	- Mucosa
MU.	- Mucous
NU. CI. SC.	- Nucleus of ciliated supporting cell
NU. RR.	- Nucleus of rod shaped receptor cell
OCI.	- Olfactory cilia
RR.	- Rod shaped receptor cell
SC. Z.	- Supporting zone
SMSA.	- Submucosa

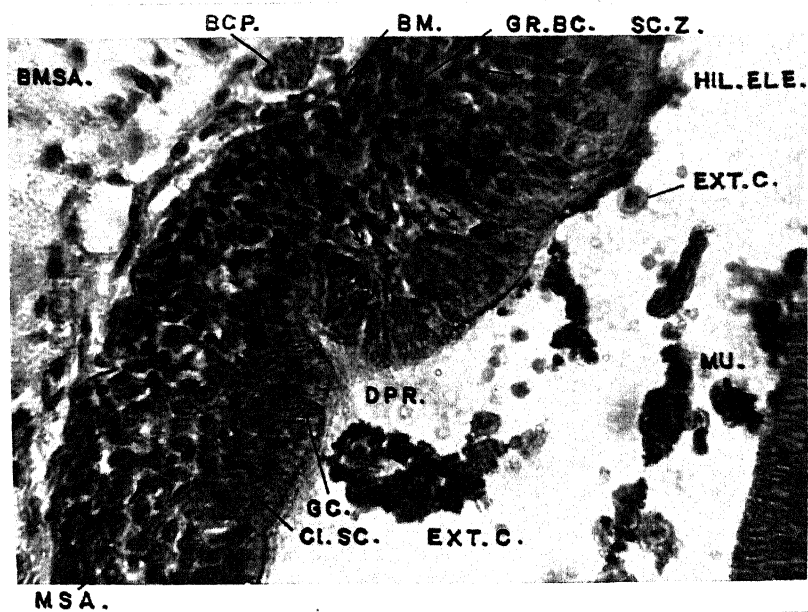


FIG. 20

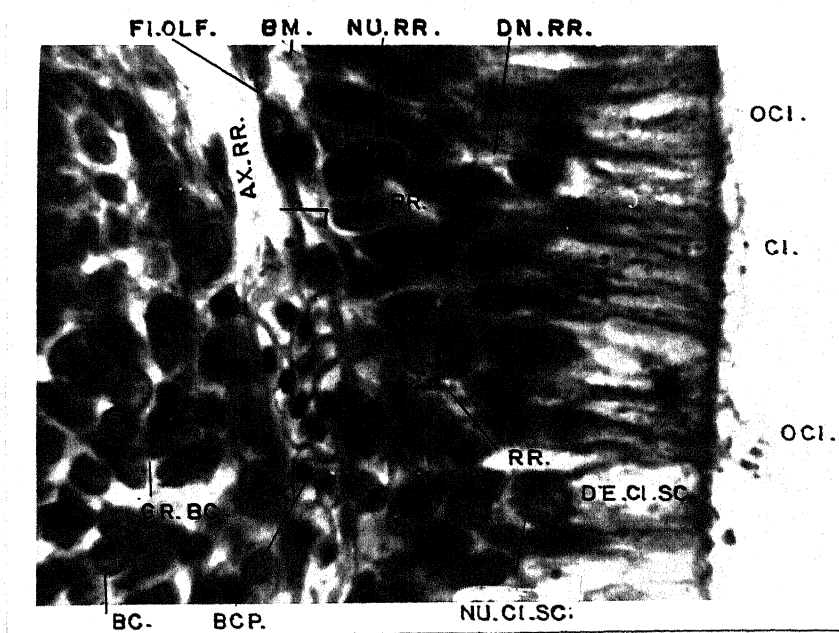


FIG. 21.

Fig. 22. Transverse section of the initial lamella of N. nandus demonstrating cellular structures of rod shaped receptors, ciliated supporting cells, basal cells, olfactory cilia and cilia. Magnification X 1000.

Fig. 23. Transverse section of the middle lamella of N. nandus showing the movement of basal cells. Folium olfactorium is clearly visible. Magnification X 1000.

AX.	- Axon
AX. RR.	- Axon of rod shaped receptor cell
AX. SR.	- Axon of spindle shaped receptor cell
BC.	- Basal cell
BM.	- Basement membrane
CI.	- Cilia
CON. TI.	- Connective tissue
DE. CI. SC.	- Distal end of ciliated supporting cell
DN. RR.	- Dendrite of rod shaped receptor cell
FI. OLF.	- Folium olfactorium
NU. CI. SC.	- Nucleus of ciliated supporting cell
NU. RR.	- Nucleus of rod shaped receptor cell
NU. SC.	- Nucleus of supporting cell
NU. SR.	- Nucleus of spindle shaped receptor cell
OCI.	- Olfactory cilia
RR.	- Rod shaped receptor cell
SR.	- Spindle shaped receptor cell
SMSA.	- Submucosa

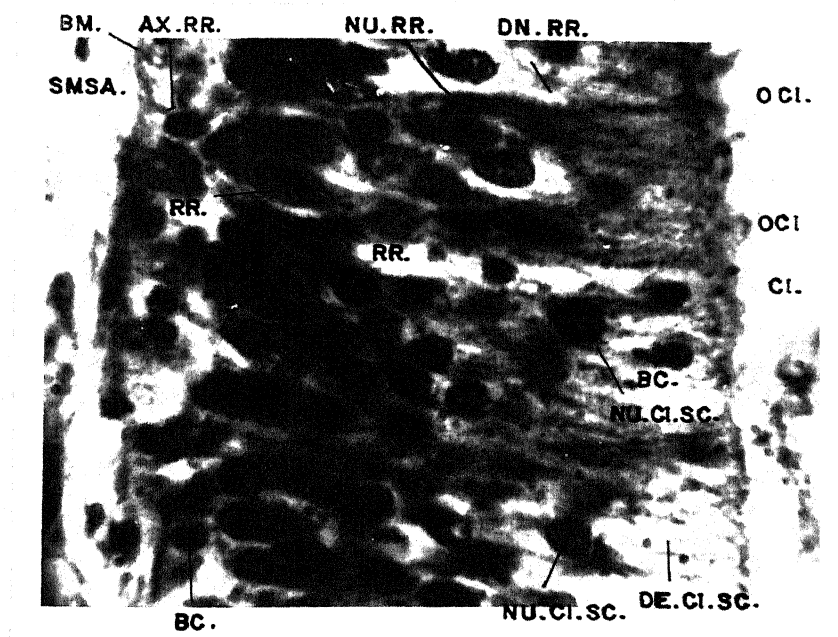


FIG. 22.

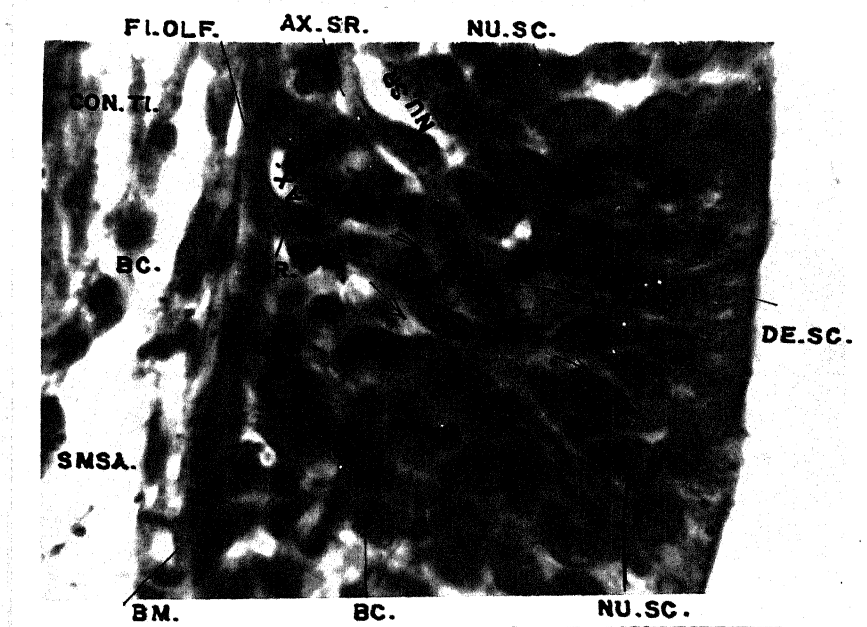


FIG. 23.

F Fig. 24. Transverse section of the hinder lamella of N. nandus showing the crypt, sunken in the submucosa with the concentration of primary neurones whose dendrites with olfactory cilia are projecting in the crypt. Magnification X 1000.

I Fig. 25. Longitudinal section passing through a single lamella of N. nandus exhibiting over activity of basal cells, with the result microformations of different patterns are visible. Magnification X 200.

AX. SR.	- Axon of spindle shaped receptor cell
BC.	- Basal cell
BC. Z.	- Basal zone
BM.	- Basement membrane
CRY.	- Crypt
DN. SR.	- Dendrite of spindle shaped receptor cell
ELE.	- Elevation
EXT. C.	- Extrusion of cell
FR. OLF. EPI.	- Floor of olfactory epithelium
GR. BC.	- Grouping of basal cell
INT. LAM. SP.	- Interlamellar space
MICRP.	- Microformations
MSA.	- Mucosa
NU. PN.	- Nucleus of primary neurone
NU. SC.	- Nucleus of supporting cell
NU. SR.	- Nucleus of spindle shaped receptor cell
OCI.	- Olfactory cilia
SC. Z.	- Supporting zone

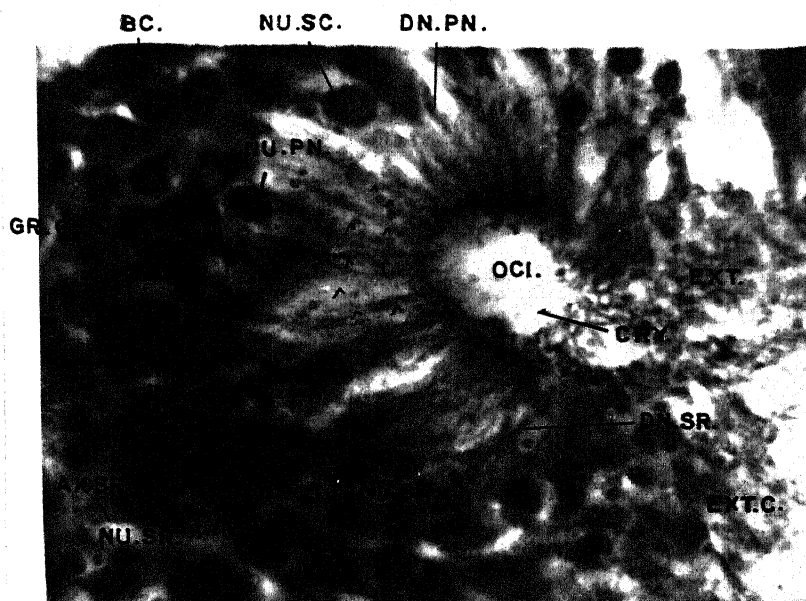


FIG. 24.

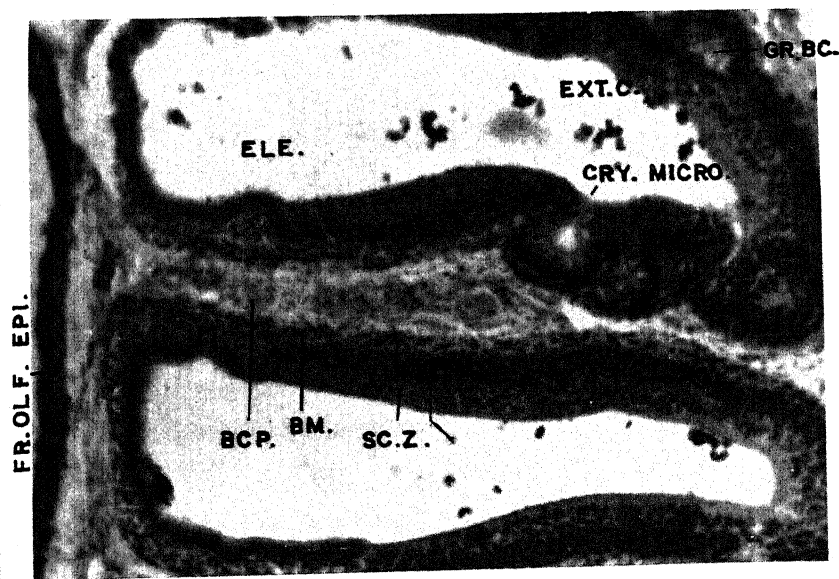


FIG. 25.

Fig. 26. Longitudinal section of the distal end of lamella of N. nandus where migration of basal cells causes the formation of vacuole like crypt, sunken in the submucosa which is also seen bifurcated in this section. Arrows demonstrating the migration of basal cells and bifurcation of submucosa. Magnification X 400.

Fig. 27. Transverse section of the middle lamella of N. nandus showing the initiation of funnel shaped crypt formation, sunken within the mucosa due to migration of basal cells. Initiation of vacuole like crypt formation is also visible. Magnification X 400.

CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
CRY.	- Crypt
DN. RR.	- Dendrite of rod shaped receptor cell
ELE.	- Elevation
EXT. C.	- Extrusion of cells
FBC.	- Fibroblast cell
FIL.	- Filiform
FN.	- Funnel
GC.	- Goblet cell
INT. LAM. SP.	- Interlamellar space
MSA.	- Mucosa
MJ.	- Mucous
OCI.	- Olfactory cilia
PN.	- Primary neurone
SMSA.	- Submucosa
VAC.	- Vacuole

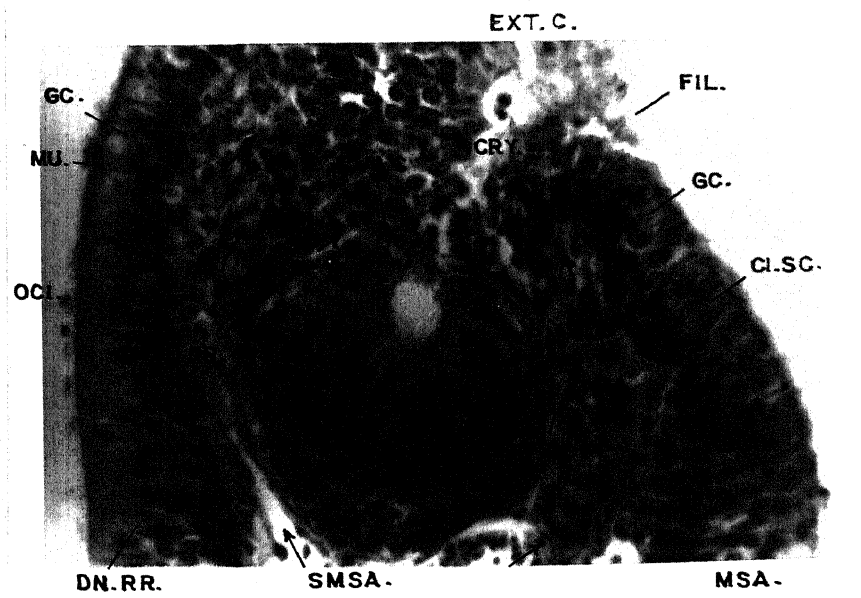


FIG. 26.

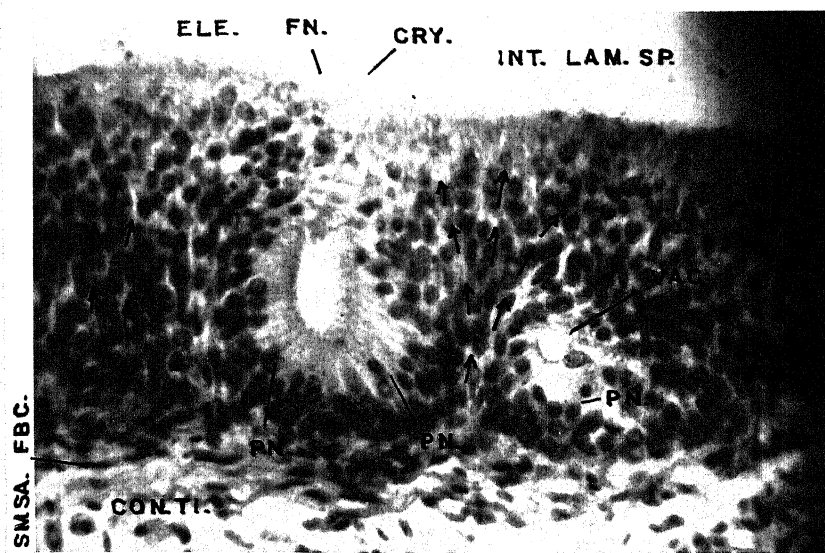


FIG. 27.



activity is observed in the olfactory rosette of N. nandus. The observation of goblet cells, at different levels in the mucosa from basal to supporting zone, demonstrates that muciferous basal cells are created in the basal zone which migrate upto the peripheral region for the discharge of their mucous into the interlamellar spaces. The goblet cells possess rounded (Fig. 19) to elongated (Fig. 11) body. They gradually grow in size and exhibit muciferous activity as they come to peripheral surface where the terminal tips of theca (TH. GC., Fig. 11) of goblet cells project in the interlamellar spaces for the easy discharge of the mucous. The goblet cell bears round to elongated theca with triangular nucleus (NU. GC.) which can be deeply stained with haematoxylin and shows its inconspicuous stalk upto the basement membrane. The chromatin material and nucleolus is not visible. Though the muciferous activity is very restricted in N. nandus because of rare occurrence of goblet cells, however, deposition of mucous in the histological sections (Figs. 20, 26, 30) in present investigation has been observed on the peripheral surface of the lamellae.

#### The basal cells:

The basal cells (BC) can be distinguished in a number of forms, lying regularly (Figs. 11, 12, 13, 14) or irregularly (Figs. 16, 18, 19, 20, 24, 26) above the basement

[illegible]

membrane and contributing a major part of the mucosa. Each basal cell is provided with a darkly stained oval nucleus (NU. BC.) with centrally placed nucleolus and uniformly distributed chromatin material. The basal cells can be seen both in mucosa and submucosa (Figs. 16, 18, 19, 23) which can be identified by their rounded shape and darkly stained nuclei. In some zones of mucosa the basal cells exhibit a tremendous tendency of migration (Figs. 18, 19, 20, 23, 25, 27, 28, 29, 30, 31) leading to different patterns of elevations and deepenings. Both these shapes are accumulated result of the large production of basal cells due to cell division and their subsequent flow in any direction, resulting unmanageable aggregation of mucosa which can be named as indifferent or transitionary mucosa. Such transitionary or indifferent mucosa becomes regularised in its form after taking the shape of deepenings and elevations. The former may be in the form of flask (FL.), vacuole (VAC.), funnel (FN.), tubule (TUB.) etc. whereas the latter alternate the deepenings in the shape of cuneiform (CUN.), filiform (FIL.), fungiform (FUNG.) and in the form of minor and major elevations (ELE., Figs. 25, 26, 27, 28, 29, 30, 31, 32). In such places submucosa becomes more activated and plays its role in supplying nutritional contents through blood circulation so as to nourish the large production of basal cells and their flow properly. The purpose of increase of olfactory



surface in different patterns may be served successfully for the proper discharge of olfactory and other functions related to olfactory epithelium.

The flow of basal cells occurs in well fed lamella and as soon as the flow is started or prior to the initiation of flow, the mucosal surface acquires the form of transitional epithelium (Figs. 18, 19, 20, 23) which in due course of time converted into formations described earlier. It is rarely observed that minor lamella (Figs. 9, 13, 14) is also a result of the flow of basal cells from the olfactory epithelium which is devoid of central core or submucosa. The minor lamella is compactly formed and it is the out pushing of mucosal zone. During the course of flow of basal cells and the formation of deepenings and elevations, the basal cells are extruded (EXT. C.) out in the interlamellar spaces (Figs. 18, 20, 25, 28, 31) which may be washed away with circulatory water current.

#### The central core or submucosa:

The central core or submucosa is greatly varied in its composition and widening in different lamellae of N. nandus (Figs. 10, 11, 14, 16, 18, 26, 32). The submucosa does not extend in microformations and elevations because these are solely made up of mucosal cellular components



(Figs. 20, 24, 26, 27, 28, 30, 31, 32). The matrix of submucosa is formed by connective tissue fibres with dense supply of fibroblasts (FBC.), histiocytes (HIS.) and basal cells (BC.). The pigment cells (PIG.) are concentrated in the olfactory rosette at the point of emergence of olfactory lamella and the surrounding of blood sinuses (BL. SI., Figs. 15, 17). The nonmedullated nerve fibres (NMN. FIB.) run below the basement membrane which join medullated nerve fibre (MN. FIB.) bundles at the point of emergence of lamella in the olfactory rosette. Branched fibroblasts and shapeless histiocytes are common in occurrence in the submucosa (Figs. 14, 15, 18, 19, 23, 30). In the initial lamellae, the submucosa is supplied with connective tissue fibres, having properly distributed fibroblasts, histiocytes and basal cells. As we proceed to hinder region of the rosette, the submucosa grows abnormally, pushing the mucosa to a thin layer (Figs. 15, 16). In such cases connective tissue fibres become irregularly distributed having a rich supply of fibroblasts, histiocytes and basal cells. Areolae are present in broadest submucosa (Figs. 10, 16). The blood capillaries (BCP.) and nonmedullated nerve fibre bundles (Figs. 11, 14, 21, 23) are observed in the submucosa of all the lamellae. The connective tissue fibres provide support to the lamellae. Specific turgor formation, for strengthening the lamellae, is not observed.

Fig. 28. Transverse section of the lamella of N. nandus exhibiting olfactory bud and funnel shaped crypts, sunken within the mucosa as a result of migration of basal cells. Arrows demonstrating the flow of basal cells. Cuneiform elevation of mucosa and extrusion of cells are also seen in the section. Magnification X 400

Fig. 29. Transverse section of lamella of N. nandus, showing flask shaped crypt and filiform elevation. Arrows demonstrating the flow of basal cells. Magnification X 400.

ARE.	- Areolae
BC.	- Basal cell
BM.	- Basement membrane
CI. SC.	- Ciliated supporting cell
CON. TI. FIB.	- Connective tissue fibre
CUN.	- Cuneiform
EXT. C.	- Extrusion of cells
FIL.	- Filiform
FL.	- Flask
FN.	- Funnel
INT. LAM. SP.	- Interlamellar space
OCI.	- Olfactory cilia
OLF. BUD.	- Olfactory bud
PN.	- Primary neurone

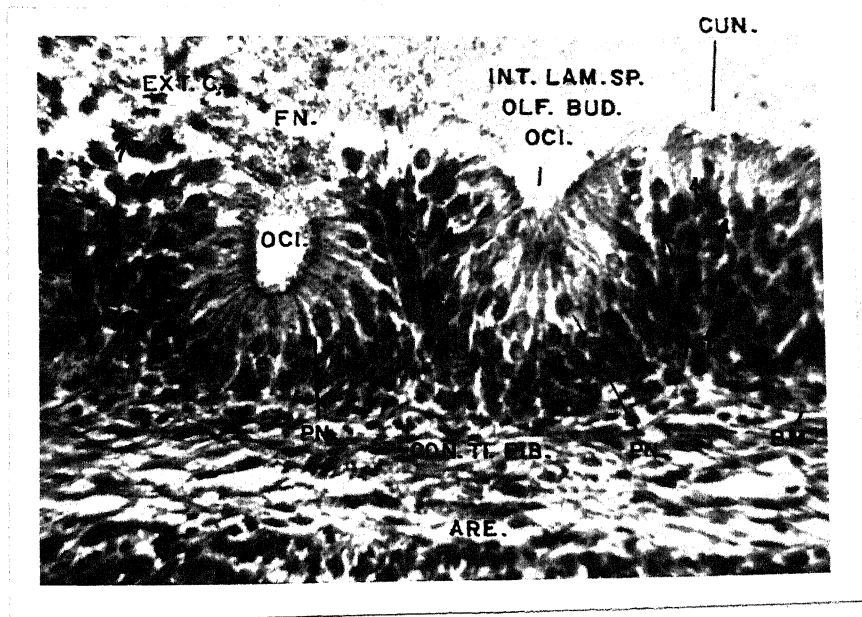


FIG. 28.

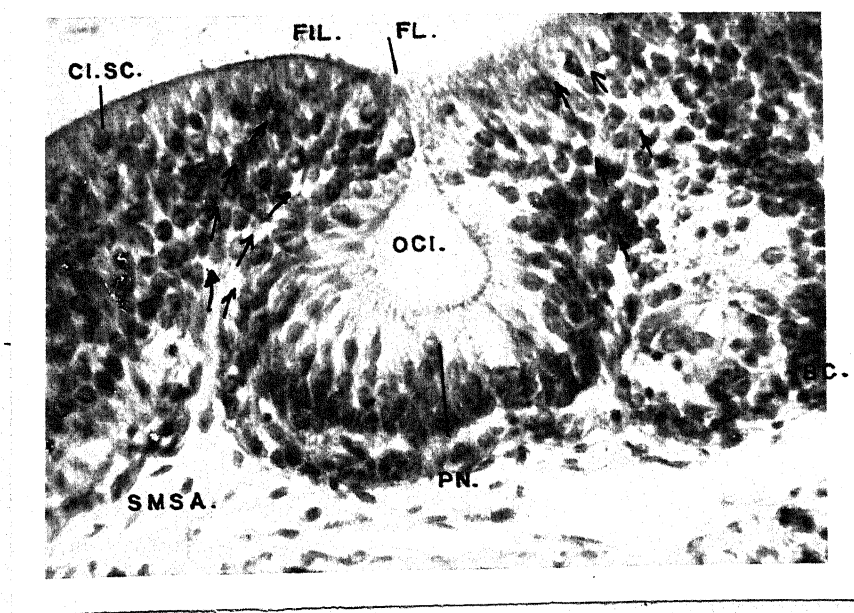


FIG. 29.

Fig. 30. Transverse section of the lamella of N. nandus showing fungiform elevation and tube like deepening. Arrows demonstrating the flow of basal cells in fungiform elevation. Magnification X 400.

Fig. 31. Transverse section of the lamella of N. nandus exhibiting cuneiform elevation with tube like deepening. Concentration of primary neurones in the form of olfactory bud is also visible. Magnification X 400.

BCP.	- Blood capillary
BM.	- Basement membrane
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
CON. TI. FIB.	- Connective tissue fibre
CUN.	- Cuneiform
EXT. C.	- Extrusion of cell
FBC.	- Fibroblast cells
FUNG.	- Fungiform
GC.	- Goblet cell
GR. BC.	- Grouping of basal cell
MU.	- Mucous
OCI.	- Olfactory cilia
OLF. BUD	- Olfactory bud
PN.	- Primary neurone
SC.	- Supporting cell
SMSA.	- Submucosa
TUB.	- Tube

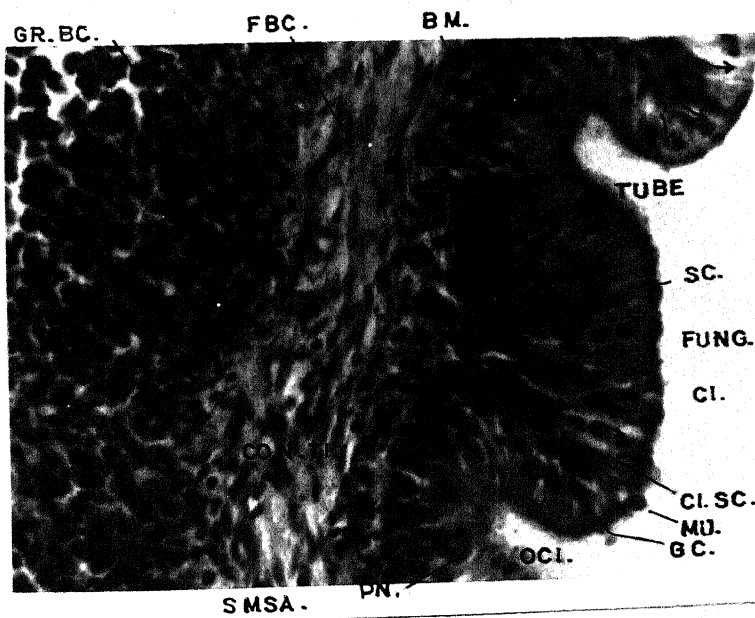


FIG. 30.

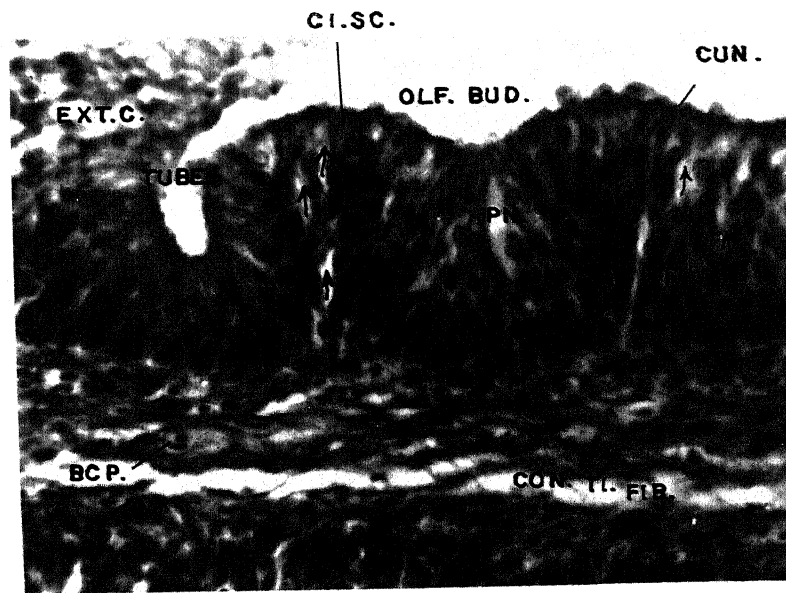


FIG. 31.

Fig. 32. T.S. of distal end of the lamella of N. nandus showing the vacuole like crypt formation in the submucosa. Bifurcation of submucosa is also clearly visible due to this specific formation. Magnification X 400.

Fig. 33. Horizontal section of the ethmoidal accessory nasal sac of N. nandus. Magnification X 100.

BC.	- Basal cell
BCP.	- Blood capillary
BM.	- Basement membrane
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
DN. PN.	- Dendrite of primary neurone
DPR.	- Depression
ELE.	- Elevation
GC.	- Goblet cell
MSA.	- Mucosa
NU. PN.	- Nucleus of primary neurone
OCI.	- Olfactory cilia
PN.	- Primary neurone
SMSA.	- Submucosa
VAC.	- Vacuole

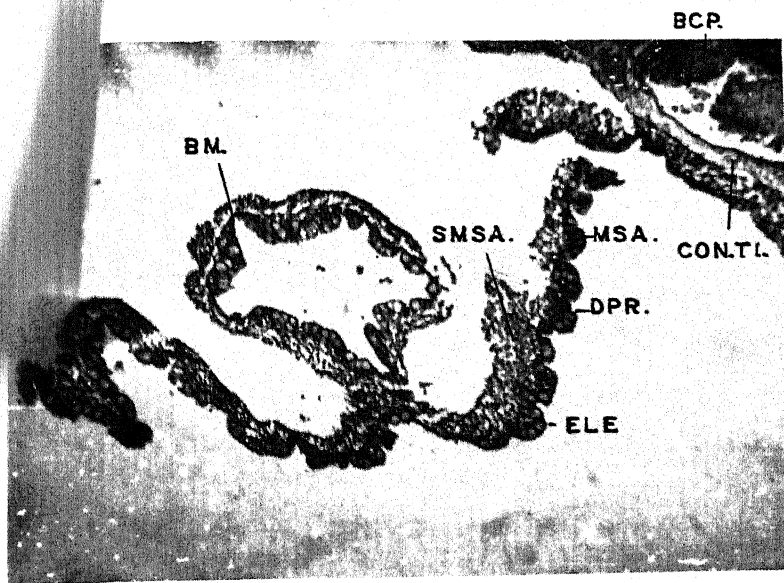
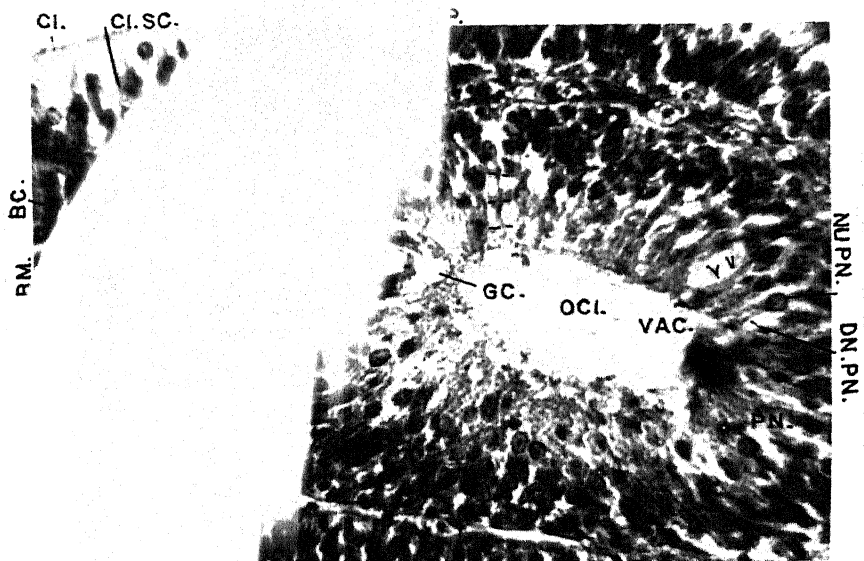


FIG. 33

Fig. 34. Cross section of ethmoidal aCcessory nasal sac of N. nandus. Magnification X 400.

Fig. 35. Cross section of lacrymal acccessory nasal sac of N. nandus. Magnification X 400.

BC.	- Basal cell
BCP.	- Blood capillary
BM.	- Basement membrane
CON. TI. FIB.-	Connective t <i>iss</i> ue fibre
DPR.	- Depression
ELE.	- Elevation
FBC.	- Fibroblast cell
GC.	- Goblet cell
NCI. SC.	- Nonciliated Supporting cell
TH. GC.	- Theca of goblet cell

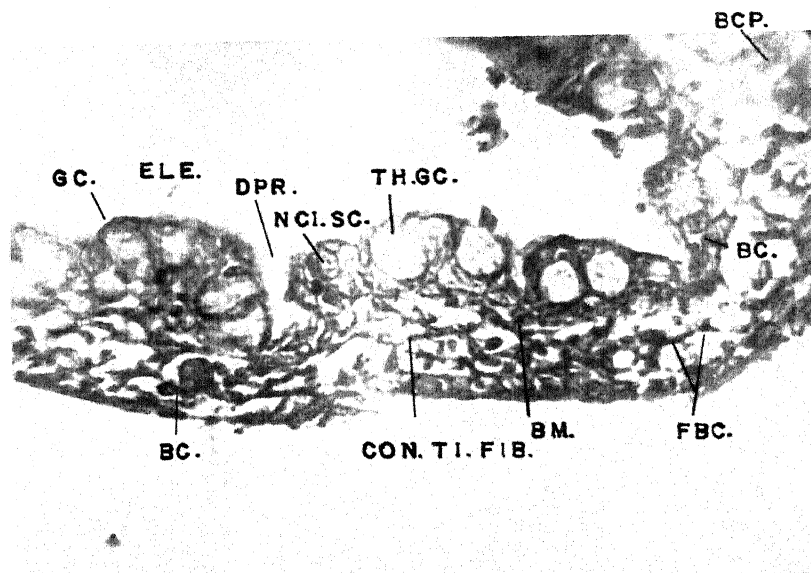


FIG. 34.

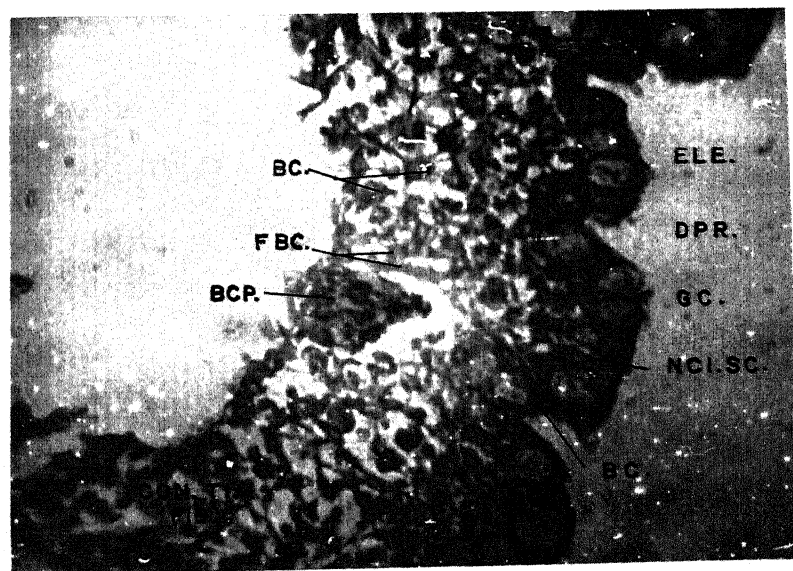


FIG. 35.

### The accessory nasal sacs:

The ethmoidal and lacrymal accessory sacs of N. nandus are made up of nonciliated cuboidal epithelium. The epithelial lining of the sacs is wavy and shows elevations and depressions. It is constituted of cuboidal supporting cells (NCI. SC.) rounded goblet cells (GC.) and basal cells (BC., Figs. 33, 34, 35).

The cuboidal cells are situated in the periphery with darkly stained oval nuclei. They can be seen in two or three rows in elevated regions of the epithelium. The goblet cells are rounded, neckless and found embedded in the peripheral epithelial surface (Figs. 34, 35). They can also be observed with empty theca after discharging their mucous. The goblet cells may also be present in two or three rows in the regions of elevations. The basal cells are lying in three or four rows just above the basement membrane. In elevations, the basal cells are accumulated in large number, showing their migratory tendency towards the periphery.

The wavy basement membrane (BM.) lies just below the basal cells. The connective tissue fibres are loosely arranged in the submucosa. The fibroblasts (FBC.) and basal cells (BC.) are intermingled with connective tissue fibres. The blood capillaries are also present in the submucosa of accessory nasal sacs (Figs. 33, 34, 35).

The number of sac layers varies with the distension of accessory sac. In a normal condition, the cuboidal epithelial and basal cells are accumulated in seven to eight layers. The connective tissue fibres and basement membrane are wavy, however, in a distended condition the accessory sac consists of 2-3 layers of basal cells and the basement membrane and connective tissue fibres are stretched. Both the ethmoidal and lacrymal accessory nasal sacs exhibit similar histological picture in the present investigation.

Fig. 36. Lateral view of the head of  
O. bimaculatus.

Fig. 37. Dissection of the head of O. bimaculatus  
from dorsal side to show the rosette  
insitu.

ANT. NAS. TUBE	- Anterior nasal tube
CEN. CH.	- Central channel
EY.	- Eye
LAM.	- Lamellae
LAM. LESS AREA	- Lamellaeless area
LING.	- Linguiform process
MAX. BAR.	- Maxillary barbel
PER. CH.	- Peripheral channel
POST. NAS. OP.	- Posterior nasal opening
RPH.	- Raphe

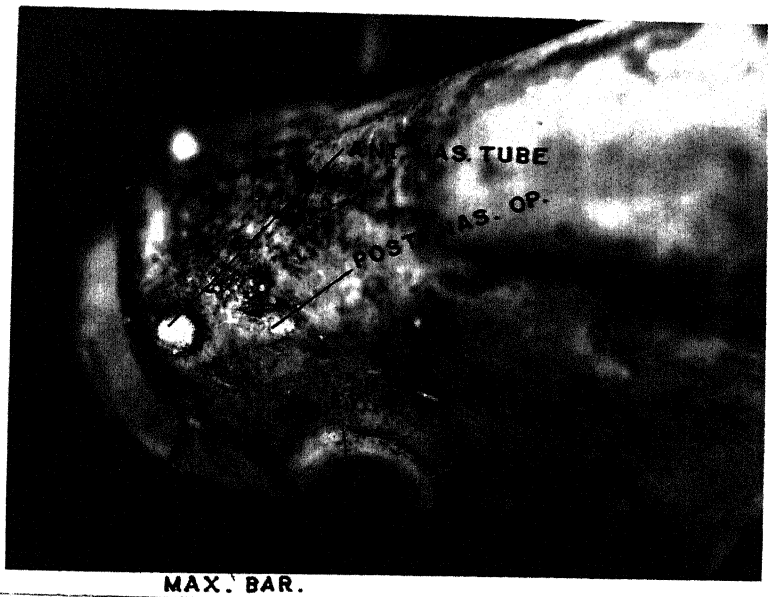


FIG. 36.

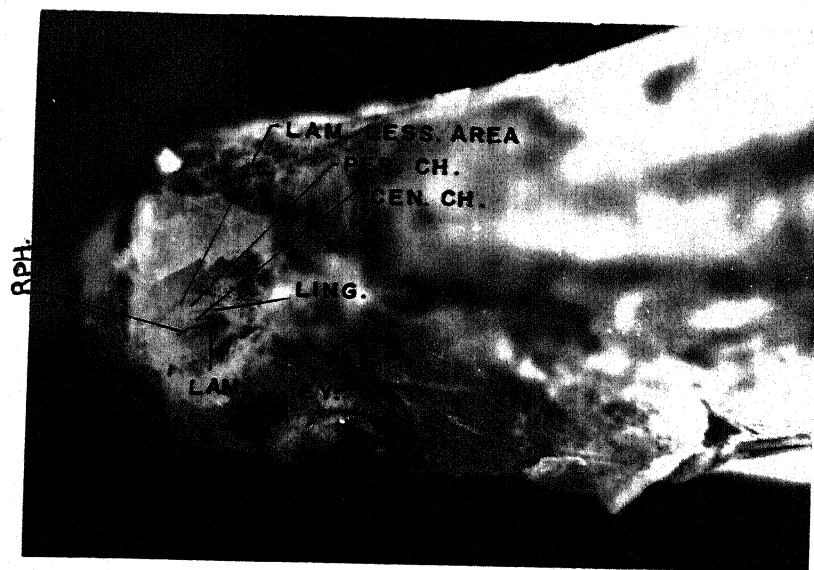


FIG. 37.

- Fig. 38A. Diagram of the dorsal view of the head of O. bimaculatus.
- Fig. 38B. Magnified sketch of anterior and posterior nasal openings with maxillary barbel of O. bimaculatus.
- Fig. 38C. Diagrammatic sketch of the rosette of O. bimaculatus to show the arrangement of lamellae.
- Fig. 38D. Diagrammatic sketch of the rosette of O. bimaculatus to demonstrate the circulation of water. Arrows indicating the entry and exit of water through nasal openings and its course of circulation within the olfactory chamber.
- Fig. 38E. A set of 1-32 lamellae from one half of the rosette of O. bimaculatus.

ANT.	- Anterior
ANT. NAS. OP.	- Anterior nasal opening
ANT. NAS. TUBE	- Anterior nasal tube
CEN. CH.	- Central channel
ETH. H.	- Ethmoidal half
EY.	- Eye
FLAP	- Flap
INTEG.	- Integument
INT. LAM. SP.	- Interlamellar space
LAC. H.	- Lacrymal half
LAM.	- Lamellae
LAM. LESS AREA	- Lamellaeless area
LING.	- Linguiform process
MAX. BAR.	- Maxillary barbel
PER. CH.	- Peripheral channel
POST.	- Posterior
POST. NAS. OP.	- Posterior nasal opening
RPH.	- Raphe

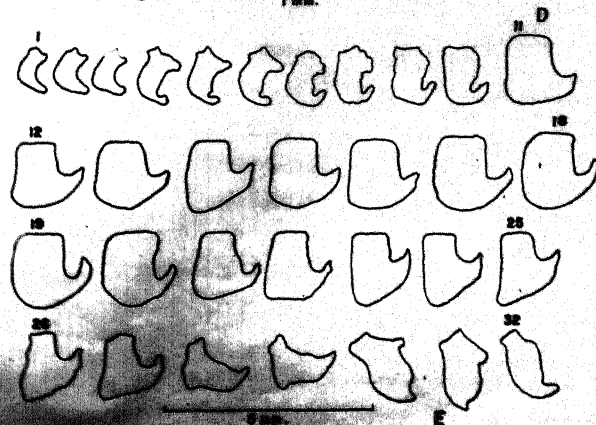
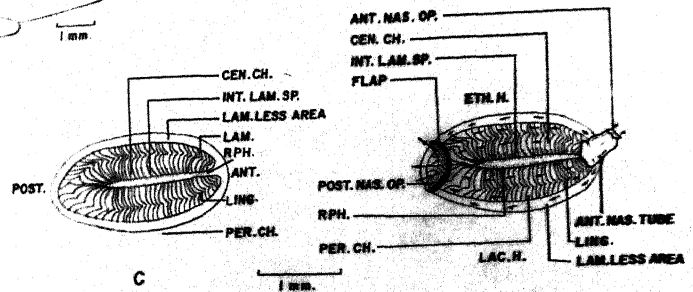
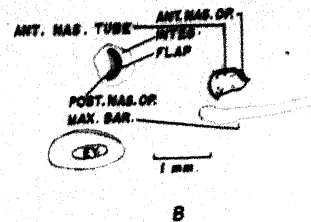
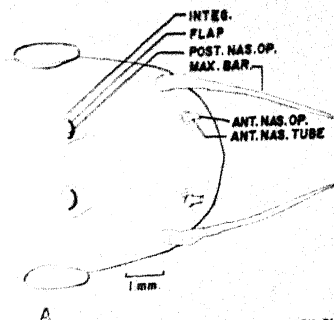


FIG. 38

Fig. 39. Diagram of the skull of O. bimaculatus.

ETH.	-	Ethmoid
FRON.	-	Frontal
LAC.	-	Lacrymal
LETH.	-	Lateral ethmoid
MAX.	-	Maxilla
NAS.	-	Nasal
OLF. FOR.	-	Olfactory foramen
PAL.	-	Palatine
PAR.	-	Parietal
PRE MAX.	-	Premaxilla
SPH.	-	Sphenoid
SOC.	-	Supraoccipital
2, 3, 4,	-	Circumorbitals

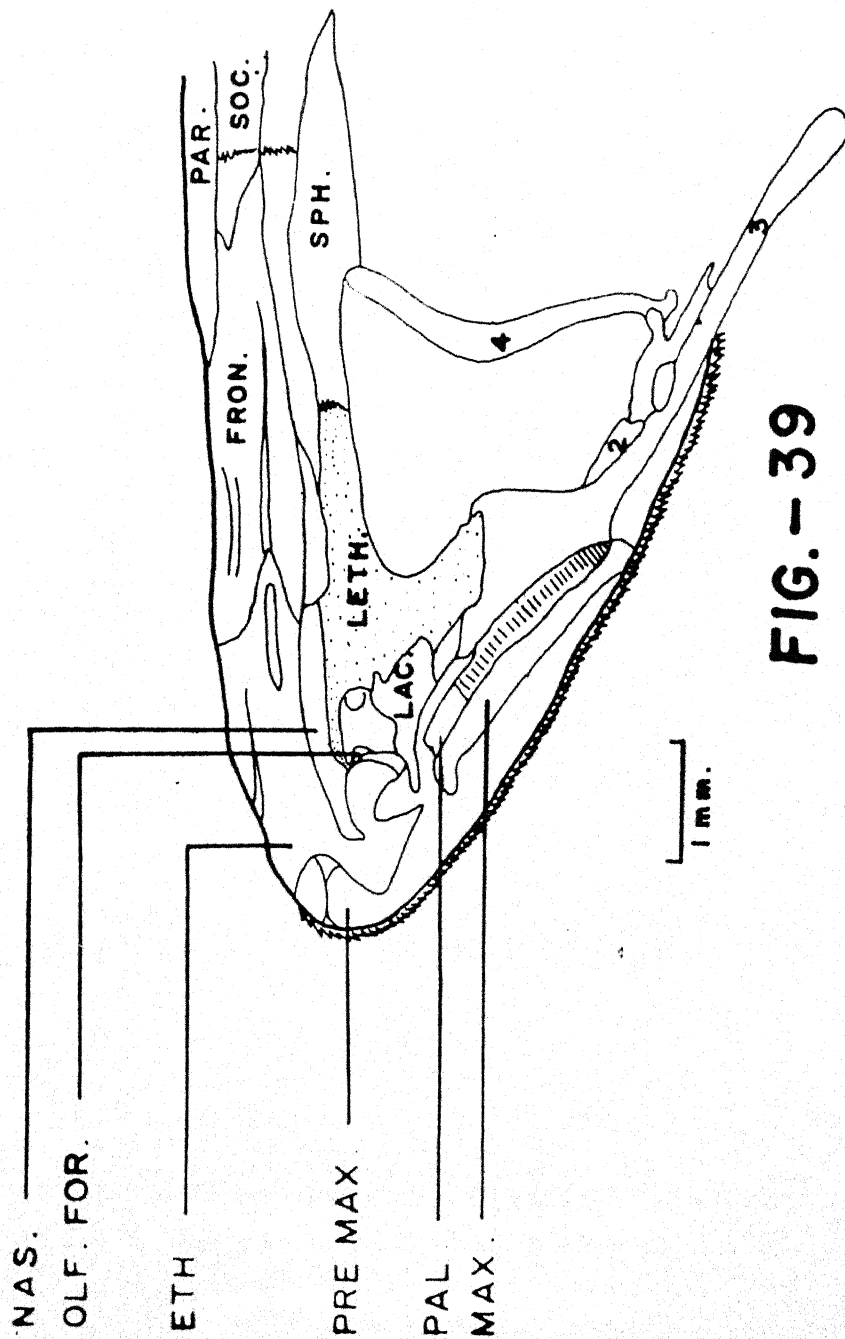


FIG.-39

Fig. 40. Diagram of the dissection of head of O. bimaculatus from dorsal side to show the relationship of brain with the rosette.

CE.	-	Cerebellum
OLF. BL.	-	Olfactory bulb
OLF. LO.	-	Olfactory lobe
OLF. TR.	-	Olfactory tract
OP. LO.	-	Optic lobe
RE.	-	Rosette

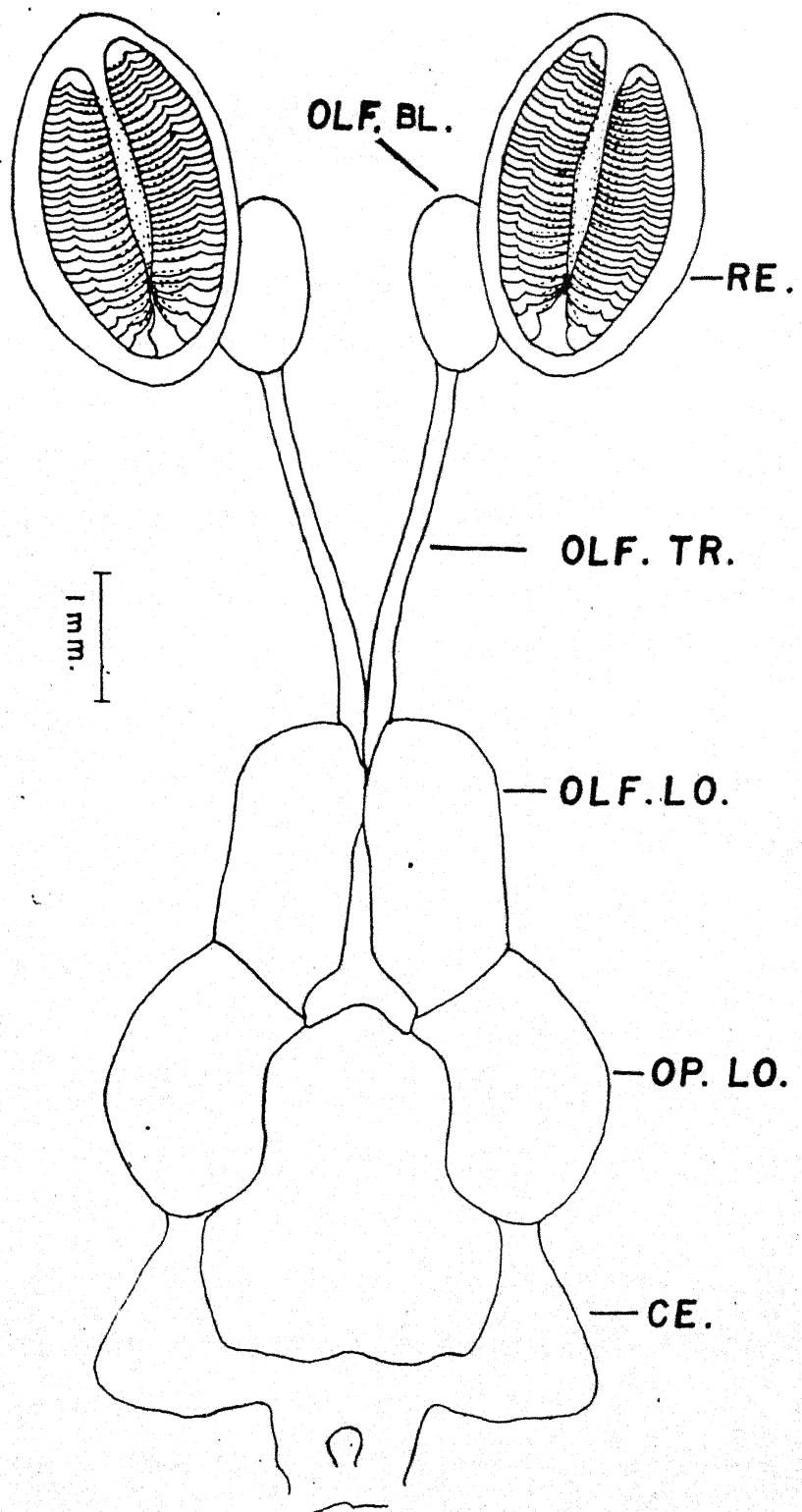


FIG.— 40



MORPHOLOGICAL OBSERVATIONS OF OLFACTORY ORGAN OF  
OMPOK BIMACULATUS (BLOCH)

Ompok bimaculatus bears a pair of olfactory chambers, situated on the dorsal surface of the head, extending from the maxilla to eye orbits. Each chamber is communicated outside by a pair of nasal openings named as anterior (ANT. NAS. OP.) and posterior nasal (POST. NAS. OP.) openings with regards to their respective positions. Both the openings demarcate two extremities of the olfactory chamber (Figs. 36, 38A, 38B). The anterior nasal opening is tubular (ANT. NAS. TUBE), projected outwardly and forwardly over the lip while the posterior is flushed with the surface of the skin of head. The latter is situated on an irregular area of integument (INTEG.) and remains covered by a loose valvular flap (VAL. FLAP), permitting the exit of water current from the olfactory chamber. The anterior nasal opening is oval in shape, lies on the underside of the tube, giving an appearance of the terminal end of the tusk, favouring the unidirectional entry of water during forward movement of the fish (Figs. 38B, 38D). This opening is situated exactly at the level of maxillary barbel (MAX. BAR.) which is emerging from the base of the tube. The movement of maxillary barbel affects the speed of entry of water current through the nasal tube and to some extent the variation in the volume of the olfactory chamber.



In a fish of 273 mm total length, the anterior and posterior nasal openings lie at a distance of 5.148 mm. The anterior nasal tube is 0.760 mm in length. The size of anterior and posterior nasal openings is 0.361 x 0.234 mm and 1.755 x 0.351 mm respectively. The latter is 1.228 mm wide after removing its valvular flap.

Each olfactory rosette (RE.) completely occupies whole of the area of olfactory chamber (OLF. CHAM.) and is elongated in shape, having ventral convex and dorsal concave surfaces. It is anteroposteriorly divided into two halves by a leaf shaped and long raphe (RPH.) which is broad in the middle and tapers sharply to posteriorward (Figs. 38C, 38D). The rosette is uniform on its both the ends however, posterior one is slightly narrow as compared to anterior. The lamellae on posterior region are elevated towards the posterior nasal opening. The raphe emerges out as a median thickening of the olfactory chamber and bears large number of lamellae (LAM.) on its either sides in a regular fashion (Figs. 37, 38C, 38D).

The lamellae are more or less flattened emerging out from the floor of olfactory chamber and remain attached to it by ventral surfaces leaving the dorsal free. They are attached by their proximal ends with the raphe and free distally. Thumb like prominent linguiform processes (LING.) are present distally on the dorsal surface of the lamellae.

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The linguiform processes of all the lamellae are seen in a definite succession, building a partition in each half of the olfactory chamber, dividing it into central (CEN. CH.) and peripheral (PER. CH.) channels. The anteriormost lamella in the rosette of O. bimaculatus is smallest and well set whereas posterior ones are comparatively enlarged and attached with the raphe obliquely, projecting upto posterior nasal opening. The middle ones are largest and attached with the raphe in an elevated manner from the surface of the olfactory chamber. The lamellae of the anterior side are smaller than those of the posterior, suggesting that the new lamellae are added towards the anterior side of the rosette. The number of lamellae shows an increasing trend with the size of the fish (Figs. 37, 38C, 38D).

The accessory nasal sacs are absent in O. bimaculatus but a regular zone of lamellaeless area is present all around the rosette. This area is supposed as an extension of the olfactory chamber and constructs an extraperipheral channel for the circulation of water. This may be treated as a compensatory device in the absence of accessory nasal sacs which keeps the water current more effectively circulating through the olfactory chamber and providing sufficient time for bathing the sensitive area in view of the reception of sensation from water.



The olfactory chamber with its rosette is lodged in a fossa formed in the ethmoidal region of the skull and is surrounded with the bony components and fibrous connective tissue. The lacrymal (LAC.) is a small triangular bone and extends anteriorly and posteriorly by two spiny processes. It covers practically the entire outer margin of the olfactory chamber from the dorsal side. The median margin of the olfactory chamber is bounded dorsally by a narrow and tubular nasal bone (NAS.) situated on the lateral margin<sup>of</sup> ethmoid (ETH.) and over the lateral ethmoid (LETH.). The deeply concave anterior face of the main body of the lateral ethmoid serves to accommodate the hinder part of the olfactory rosette. The anterior part of the olfactory chamber is supported ventrally by the anterolateral process of the ethmoid and a portion of premaxilla (PREMAX.), extending between the ethmoid and maxilla (MAX.). The anterior surface of the olfactory chamber as well as the middle surface of its anterior part are bound by the anterolateral process of the ethmoid. The outer surface of the anterior part of the chamber is bounded by a rod like maxilla and small irregular palatine (PAL., Fig. 39).

The main body of the lateral ethmoid is scooped out medially to receive the globular olfactory bulb (OLF. BL.) which lies along the hinder middle surface of the olfactory rosette. The olfactory bulb receives the bundles of olfactory fibres from the ventral surface of the olfactory

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rosette. The paired olfactory tracts are narrow and much elongated. Each tract arises from the olfactory bulb and runs backward through the frontal region of the skull(Fig.40).

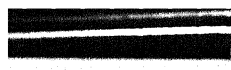
After removing the ethmoid, lateral ethmoid and frontal (FRON.) from the dorsal side of the head, the brain and its relation to the olfactory rosette become clearly exposed. The olfactory bulbs are situated close to the posteroventral surface of the rosette and receive nerve fibres from each lamella. The olfactory bulbs are anteriorly broad and become narrow posteriorly which are joined with telencephalon (OLF. LO.) by thick olfactory tract (OLF. TR.). The mesencephalon (OP. LO.) is slightly better developed as compared to the telencephalon. The size of the brain and its lobes is found increasing successively with respect to the increasing size of the fish (Table 2, Fig. 40).

#### Ecological coefficient:

The usual methods are adopted for the calculation of ecological coefficient in the fishes varying from 168 mm to 273 mm total length. The length of brain and number of lamellae undergo considerable increase with respect to the size of the fish. In the present investigation, the brain of fish varies from 9.652 to 13.572 mm with the result mesencephalon ranges from 2.398 to 3.159 mm whereas the telencephalon from 2.106 to 2.632 mm (Table 2).

Table 2. Ecological coefficient of Ompok bimaculatus

Sl. No.	Total length (mm)	Number of lamellae Rosette		Total length of brain (mm)	Length of mesencephalon (mm)	Length of telencephalon (mm)	Ecological coefficient (Through lobes of brain) Length of telencephalon x 100 Length of mesencephalon	Retinal area of both eyes (mm <sup>2</sup> )	Olfactory area of both rosette (mm <sup>2</sup> )	Ecological coefficient (through area) Olfactory area x 100 Retinal area
		Right	Left							
1	168	64	64	9.652	2.398	2.106	87.823	30.221	167.951	555.742
2	172	64	65	9.711	2.457	2.106	85.714	30.442	231.327	759.894
3	225	82	82	11.115	2.808	2.340	83.333	43.531	303.853	698.015
4	249	100	102	13.104	3.100	2.515	81.129	71.070	399.836	562.594
5	273	104	104	13.572	3.159	2.632	83.317	77.419	486.882	628.892
Average				11.430	2.784	2.339	84.263	50.536	317.969	641.027



7

The area of both the retinae and that of two rosettes are calculated by the method suggested by Teichmann (1954) and further modified by Rahmani and Khan (1981). It is found that former ranges from 30.221 to 77.419 mm<sup>2</sup> and that of latter from 167.951 to 486.822 mm<sup>2</sup>.

By calculating the ecological coefficient from brain lobe method it stands 84.263 per cent as an average of all the findings. Similarly the ecological coefficient calculated by area method ranges from 555.742 to 759.894 per cent and 641.027 per cent as an average (Table 2).

The above observations indicate that O. bimaculatus possesses considerably developed olfactory faculty inclining towards the macrosmatic characteristic. The ecological coefficient, calculated by brain lobe method, reveals that optic centre in brain shows a very little dominance over the olfactory centre. This dominance is not as prominent as that of olfactory area of both the rosette. Hence O. bimaculatus is a nose fish as its nocturnal habit put a weightage to its trend of dependence on olfactory as compared to that of optic faculty.

The route of water circulation through the olfactory chamber of O. bimaculatus:

The movement of maxillary barbels (MAX. BAR.) and the jaw action synchronise with unidirectional ciliary



movement, conduct water current through anterior tubular nasal opening. Forwardly and outwardly directed tube with underside anterior nasal opening assists in smooth and continuous entry of water during the course of swimming of fish. The water falls on the anterior part of rosette as it is well set and provides more space for incoming water current. The more water is accommodated in the lamellaeless area in the form of extraperipheral channel (LAM. LESS AREA, Fig. 38C) all around the rosette.

After the reception of water in the anteriormost part of the rosette, it circulates in the central and peripheral channels (CEN. CH., PER. CH.) of the olfactory chamber. The water current takes a whirling shape in the posterior region where elevated and obliquely attached lamellae over this circulating water. The water present in extraperipheral channel is utilized for effective involvement of olfactory surface with it. With the result of posterior valvular nasal opening, the water is allowed to exit with force. This permits more stay of water within the olfactory chamber which provides sufficient time for the olfactory reception through the water (Fig. 38D).

Fig. 41. Horizontal section of the rosette of O. bimaculatus showing the arrangement of lamellae on either sides of the raphe. The lamellaeless area encapsulating the rosette is also visible. Magnification X 50.

Fig. 42. Horizontal section of anterior part of the rosette of O. bimaculatus displaying the arrangement of the lamellae with the raphe in the middle and lamellaeless area in their periphery. Magnification X 100.

ANT. LAM.	-	Anterior lamellae
BM.	-	Basement membrane
CI.	-	Cilia
DE. LAM.	-	Distal end of lamella
INT. LAM. SP.	-	Interlamellar space
LAM. LESS AREA	-	Lamellaeless area
MSA.	-	Mucosa
POST. LAM.	-	Posterior lamellae
PRO. LAM.	-	Proximal end of lamella
RPH.	-	Raphe
SMSA.	-	Submucosa

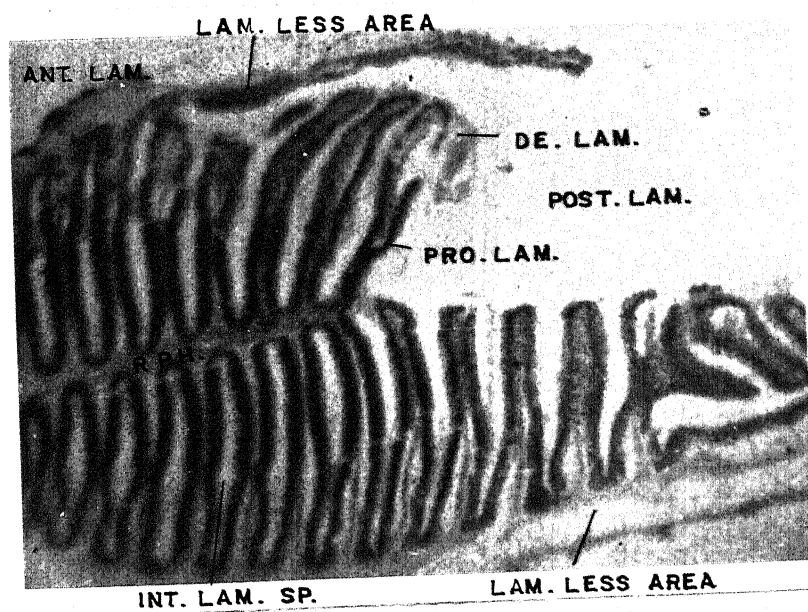


FIG. 41.

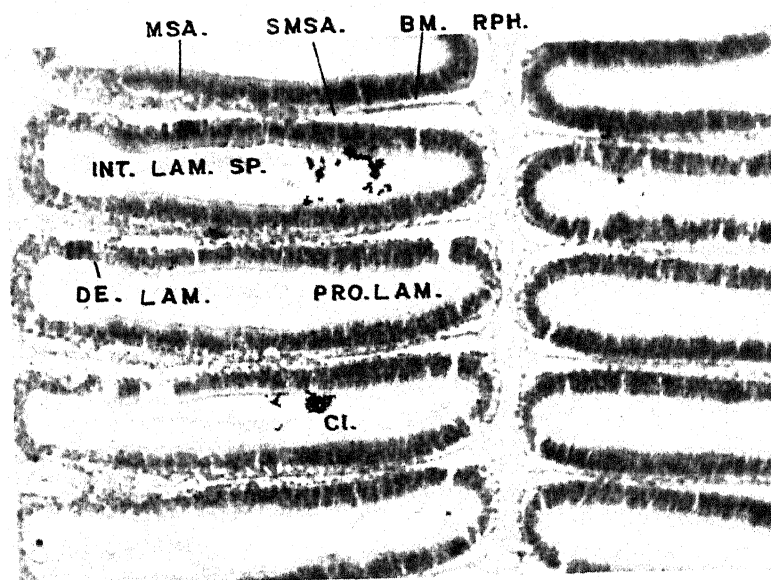


FIG. 42.

Fig. 43. Horizontal section of the rosette of O. bimaculatus passing through the posterior lamellae, showing lamellar structure with respect to their proximal and distal regions. Lamellaeless area and raphe are also visible. Magnification X 100.

Fig. 44. Longitudinal section of the anterior lamella of O. bimaculatus, displaying the cellular composition of mucosa and submucosa. Magnification X 400.

BC.	- Basal cell
BCP.	- Blood capillary
BC. Z.	- Basal zone
BM.	- Basement membrane
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
DE. LAM.	- Distal end of lamella
DN. RR.	- Dendrite of rod shaped receptor cell
EXT. C.	- Extrusion of cells
GC.	- Goblet cell
LAM. LESS AREA	- Lamellaeless area
MSA.	- Mucosa
NU. RR.	- Nucleus of rod shaped receptor cell
OCI.	- Olfactory cilia
PRO. LAM.	- Proximal end of lamella
RPH.	- Raphe
SC. Z.	- Supporting zone
SMSA.	- Submucosa

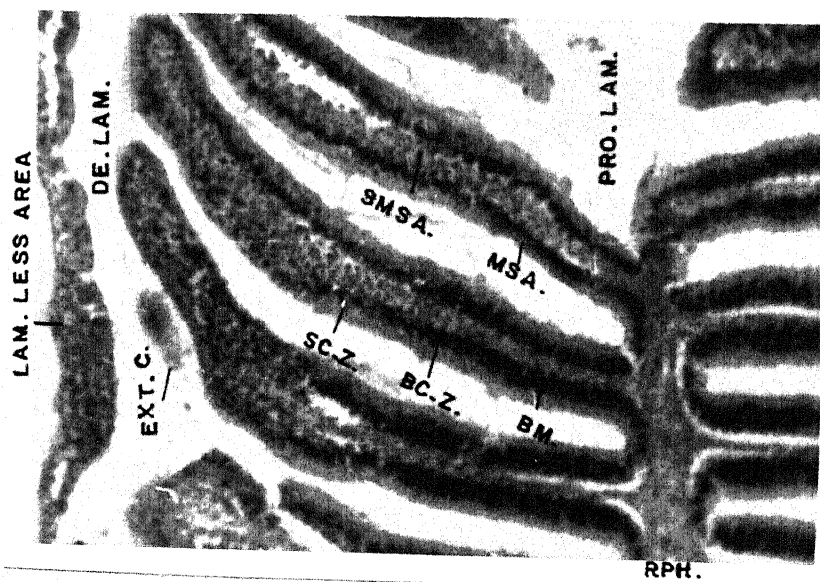


FIG. 43.

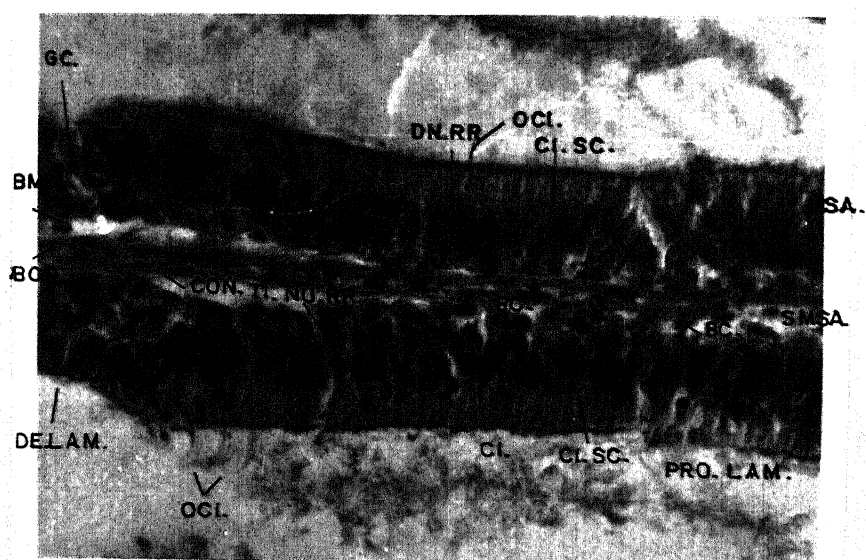


FIG. 44.

HISTOLOGICAL OBSERVATIONS OF OLFACTORY ORGAN OF  
OMPOK BIMACULATUS (BLOCH)

The olfactory rosette of O. bimaculatus is fully lodged in the olfactory chamber and thrown into number of lamellae, attached on either sides of the raphe, a median anteroposterior thickening of the olfactory epithelium, dividing the rosette into two clear halves. The olfactory rosette is encapsulated by the extension of olfactory epithelium which forms continuous girdle like lamellaeless area (LAM. LESS AREA) all around the rosette (Figs. 37, 38C, 41). The lamellae maintain interlamellar spaces (INT. LAM. SP.) in between them. Each lamella is made up of central core or submucosa (SMSA.) lined on either sides by a well composed cellular zone of mucosa (MSA.). The basement membrane (BM.) stands as partition in between the mucosa and submucosa (Figs. 42, 43, 44).

On the basis of cellular composition, the lamellae may be divided into anterior and posterior ones. The former represents larger group of lamellae (Figs. 41, 42) whereas the latter few in number with enormously enlarged body (Figs. 41, 43).

The anterior lamellae (ANT. LAM.) are having compact cellular organisation and possess almost uniform body. The central core and mucosa are uniformly built. The

posterior lamellae (POST. LAM.) are having wide central core or submucosa with scattered cellular organisation of mucosa (Fig. 43).

Each lamella is divisible into proximal (PRO. LAM.) and distal (DE. LAM.) zones from the point of view of the distribution of cellular components. The former zone extends on either sides of the raphe upto the middle region of the olfactory rosette while the latter from the middle of the olfactory rosette to encapsulation of the lamellae-less area. It is observed that the anterior lamellae possess larger bulk of well built proximal zone (Figs. 42, 44, 45, 50) whereas this zone decreases as we proceed posteriorward. In posterior lamellae, the proximal zone restricts on either sides of the raphe whereas distal zone occupies most of the length of lamellae, showing scattered distribution of cellular components in mucosa and submucosa (Figs. 43, 46). The distal zone is lesser in anterior lamellae. The submucosa in posterior lamellae is comparatively broader which may be of variable degree and matrix composition.

The proximal zone in anterior lamellae exhibits dense cellular composition and mucous cells occur rarely. This zone is heavily ciliated and richly supplied with ciliated supporting cells, intermingled with spindle shaped receptor cells.

The distal zone is lined by nonciliated supporting cells which show positive muciferous activity, revealing the existence of goblet cells (Figs. 46, 51). This zone is richly supplied with receptor cells which may be observed at different levels of the olfactory epithelium. Extrusion of cells and mucous discharge can be observed in this zone. The submucosa in this zone is enormously developed pushing the mucosa to a thin layer (Fig. 43). The fragment of connective tissue in spacious submucosa is a characteristic of distal zone of posterior lamellae.

#### The lamellaeless area:

The lamellaeless area is a nonsensitive zone of olfactory epithelium, devoid of receptor cells but richly exhibiting positive muciferous activity. It is made up of thick zone of basal cells, showing their grouping and un-uniform distribution in number of layers. The supporting zone is made up of nonciliated supporting cells (NCI. SC.) where nuclei are clearly visible. This zone is richly supplied with goblet cells and mucous discharge entangles the foreign material (Figs. 48, 53), circulating with water current. The unwanted foreign bodies or materials are held up in mucous discharge in the lamellaeless area, permitting clear water through interlamellar spaces (Figs. 48, 53).

The olfactory epithelium of O. bimaculatus exhibits following cellular components: supporting cells, receptor cells, goblet cells and basal cells.

**The supporting cells:**

The supporting cells are arranged perpendicularly to the central core of lamellae and contribute in the formation of greater bulk of the olfactory epithelium. They can be distinguished as ciliated supporting cells (CI. SC., Figs. 45, 50), nonciliated supporting cells (NCI. SC., Figs. 46, 48, 51) and transitionary supporting cells (TSC.), showing muciferous activity.

The ciliated supporting cells are tall and richly ciliated. They are confined in the proximal part of the lamellae on either sides of the raphe. In anterior lamellae the ciliated supporting cells may range upto the middle of the rosette whereas in posterior ones they are present in very limited zone. The arrangement of these cells in the olfactory epithelium is compact (Figs. 45, 50). The ciliated supporting cells are columnar in nature and made up of proximal or inner limb and distal (DE. CI. SC.) or outer limb. The later is broad and elongated, extending upto the peripheral surface of the lamellae while the former is short, inconspicuous and extends upto the basement membrane. The cytoplasm of these cells shows granular

appearance. The distal end of these cells bear cilia (CI.) which project into the interlamellar spaces. The cilia are planted on the basal granules. The nucleus (NU. CI. SC.) of ciliated supporting cell is situated in the proximal or inner limb and is of spherical or oval in shape. An acentrally situated nucleolus is visible and chromatin material is evenly distributed in the karyoplasm. The nucleus of ciliated supporting cell takes sharp stain of haematoxylin but the limbs are eosinophilic (Figs. 45, 50).

The nonciliated supporting cells (NCI. SC.) are confined in the olfactory epithelium of distal zone of the lamellae and lamellaeless area, encapsulating the olfactory rosette (Figs. 46, 48, 51). They are short and nonciliated provided with oval nuclei, situated in their distal or outerlimbs just above the basal zone. The proximal or inner limb is visible due to scattered distribution of cellular components in basal and supporting zones. Intercellular spaces are commonly visible among the cells, distributed in this zone. The nucleus (NU. NCI. SC.) of nonciliated supporting cell takes a dark stain with faintly visible chromatin material and nucleolus. The cells, present in the lamellaeless area of olfactory epithelium, are comparatively short and forming thick supporting zone. The nucleus, in the supporting cells of lamellaeless area, is very clear but nucleolus and chromatin material are faintly visible.

Fig. 45. Transverse section of the anterior lamella of O. bimaculatus passing through its middle region, showing cellular details related to receptors, ciliated supporting cells, connective tissue and other finer structures. Magnification X 1000.

Fig. 46. Transverse section of the posterior lamella of O. bimaculatus, passing through its distal region, showing cellular structure with special reference to synapse establishment between the dendrite of spindle shaped receptor cell and axon of primary neurone. Magnification X 1000.

AX. RR.	- Axon of rod shaped receptor cell
BC.	- Basal cell
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
DE. CI. SC.	- Distal end of ciliated supporting cell
DE. NCI. SC.-	- Distal end of nonciliated supporting cell
DN. PN.	- Dendrite of primary neurone
DN. RR.	- Dendrite of rod shaped receptor cell
FBC.	- Fibroblast cell
FI. OLF.	- Folium olfactorium
GR. BC.	- Grouping of basal cells
HIS.	- Histiocyte
NU. PN.	- Nucleus of primary neurone
NU. RR.	- Nucleus of rod shaped receptor cell
NU. SR.	- Nucleus of spindle shaped receptor cell
OCI.	- Olfactory cilia
PN.	- Primary neurone
RR.	- Rod shaped receptor cell
SR.	- <u>Spindle shaped receptor cell</u>
SY.	- Synapse
TBC.	- Transitional basal cell
TH. GC.	- Theca of goblet cell
TSC.	- Transitional supporting cell

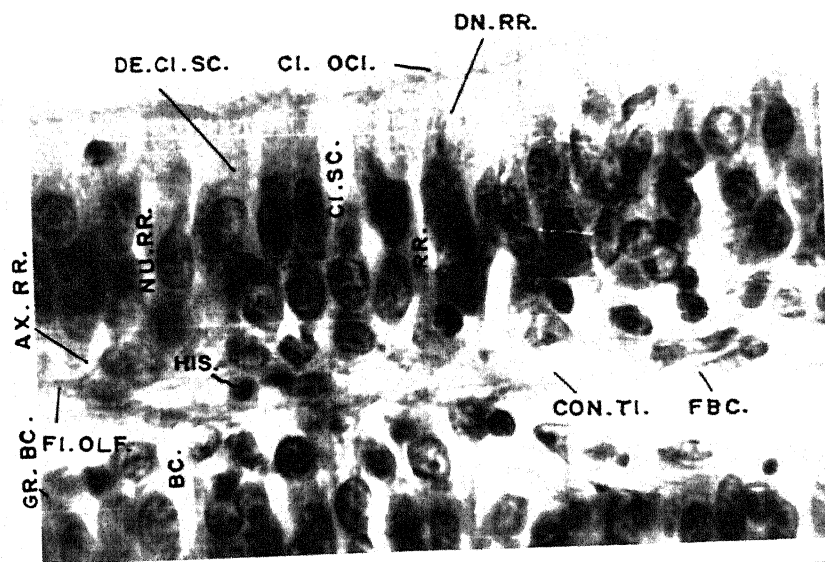


FIG. 45.

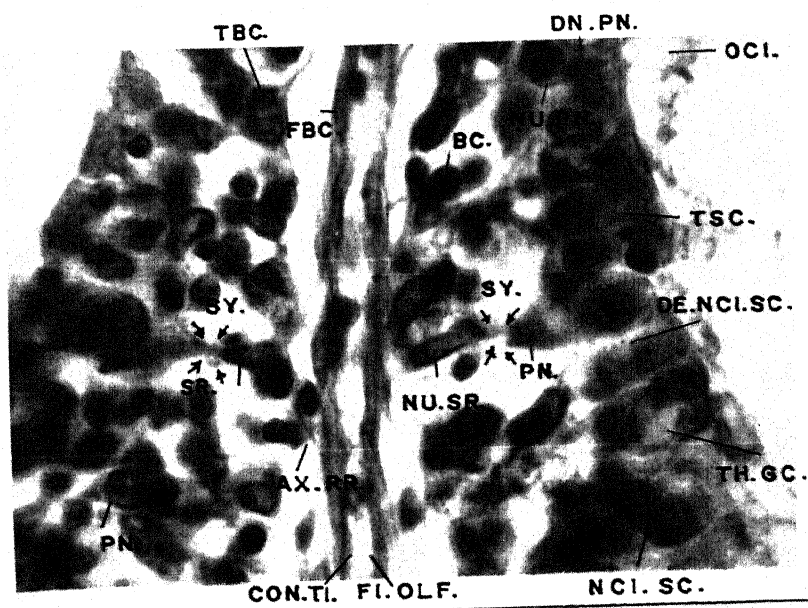


FIG. 46.

Fig. 47. Transverse section of the lamella of O. bimaculatus passing through its proximal region, attached with raphe, exhibiting greater concentration of primary neurones with their dendrites projecting in the interlamellar space. Magnification X 1000.

Fig. 48. Transverse section of lamellaeless area of the rosette of O. bimaculatus exhibiting muciferous activity with greater concentration of basal and goblet cells. Magnification X 400.

BC.	- Basal cell
BM.	- Basement membrane
CON. TI.	- Connective tissue
DN. PN.	- Dendrite of primary neurone
DN. SR.	- Dendrite of spindle shaped receptor cell
FBC.	- Fibroblast cell
FGN. MU.	- Foreign material entangled in mucous
HIS.	- Histiocyte
LAM.	- Lamella
MU.	- Mucous
NCI. SC.	- Nonciliated supporting cell
NU. PN.	- Nucleus of primary neurone
NU. NCI. SC.	- Nucleus of nonciliated supporting cell
NU. SR.	- Nucleus of spindle shaped receptor cell
OCI.	- Olfactory cilia
TBC.	- Transitional basal cell
TH. GC.	- Theca of goblet cell
TSC.	- Transitional supporting cell

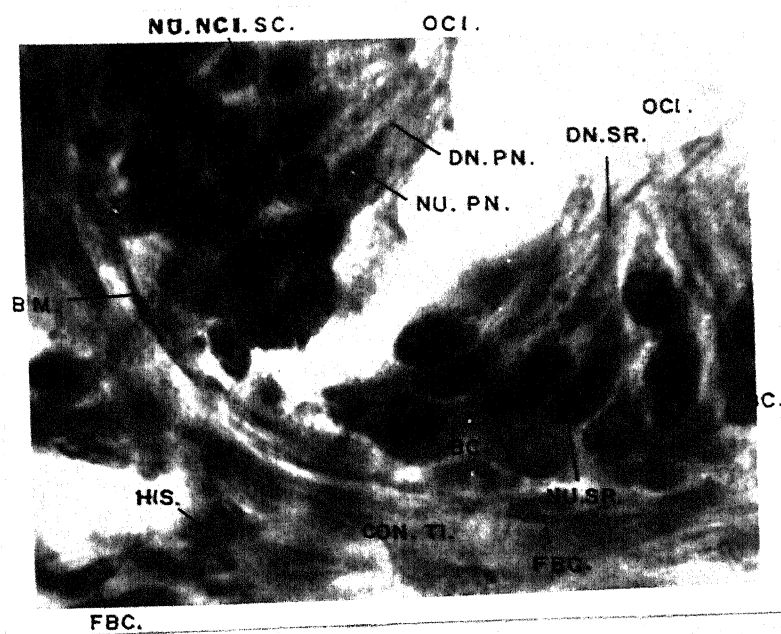


FIG. 47.

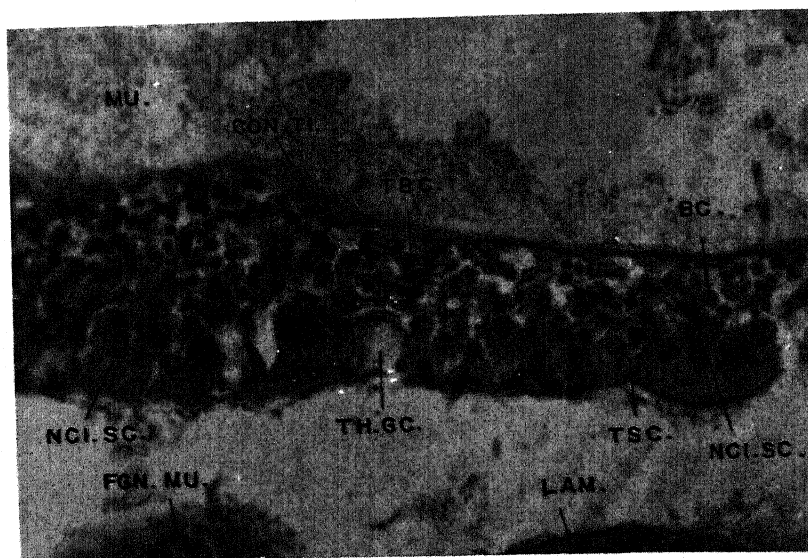


FIG. 48.

Fig. 49. Transverse section of the anterior lamella of O. bimaculatus passing to its middle region, displaying the cellular details of submucosa and mucosa with special reference to primary neurone and spindle shaped receptor cells with their axons and dendrites. Magnification X 1000.

Fig. 50. Transverse section of the anterior lamella of O. bimaculatus showing rod shaped receptor cells with their axonic and dendritic extensions. Magnification X 1000.

AX.	- Axon
BC.	- Basal cell
BCP.	- Blood capillary
CI.	- Cilia
CON. TI.	- Connective tissue
DE. CI. SC.	- Distal end of ciliated supporting cell
DN. PN.	- Dendrite of primary neurone
DN. RR.	- Dendrite of rod shaped receptor cell
FBC.	- Fibroblast cell
GR. BC.	- Grouping of basal cells
HIS.	- Histiocyte
NU. CI. SC.	- Nucleus of ciliated supporting cell
NU. PN.	- Nucleus of primary neurone
NU. RR.	- Nucleus of rod shaped receptor cell
NU. SR.	- Nucleus of spindle shaped receptor cell
OCI.	- Olfactory cilia
PN.	- Primary neurone
SR.	- Spindle shaped receptor cell
TBC.	- Transitional basal cell

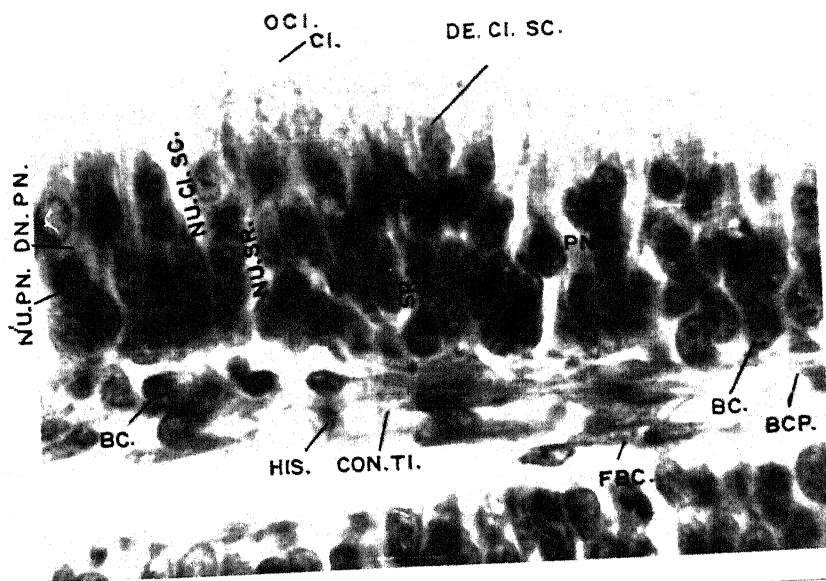


FIG. 49.

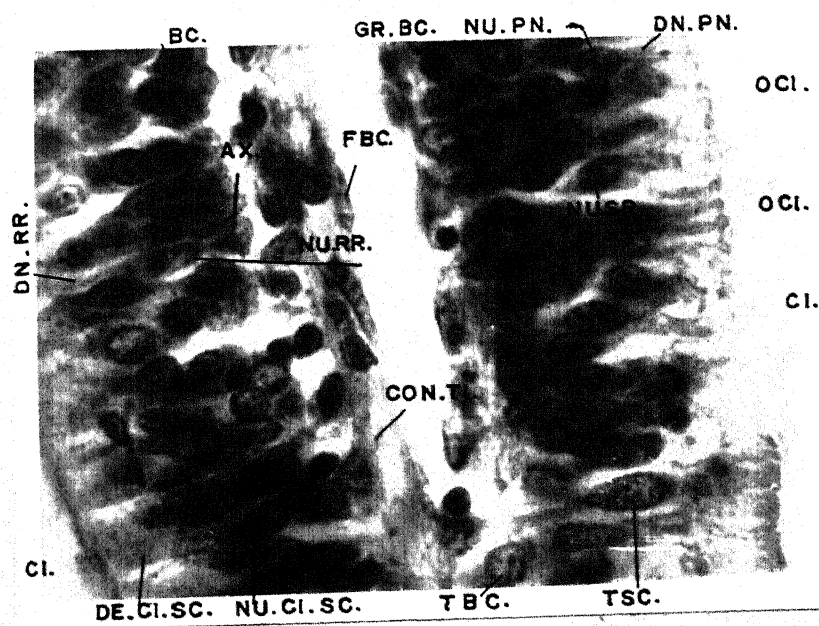


FIG. 50

Some nonciliated supporting cells, in the distal zone of lamellae as well as the lamellaeless area, exhibit positive muciferous activity, demonstrating their transitional nature. Such cells can be observed in different formative stages, showing their body filled with mucous or in a stage of discharging mucous or empty theca of goblet cells (Figs. 46, 48, 51). In the phase of transformation of a supporting cell, the nucleus and chromatin material are compressed downward in the form of triangular knob which may remain attached with the basement membrane by a filamentous limb or stalk of the goblet cell.

#### The receptor cells:

The receptor cells are distributed everywhere in the olfactory epithelium except the lamellaeless area. They are present in the distal zone and also in the proximal part of the lamellae. Any form of accumulation or grouping of receptors is not observed in the olfactory epithelium of Q. bimaculatus. They occur in solitary form, however, in the distal zone of lamellae, occasional synapsis establishment, between the axon of primary neurone and dendrite of spindle shaped receptor cells, is observed (Fig. 46). The receptor cells in Q. bimaculatus may be primary neurones, spindle and rod shaped receptor cells.

The rod shaped receptor cells (RR.) are taking a shape of giant cells and visible in the proximal zone of lamellae among the ciliated supporting cells (CI. SC.). Dendrites of these cells are observed intermingled with the distal limb of ciliated supporting cells. They are having elongated body, sending dendrites and axons towards the distal and proximal zones of the mucosa respectively. The cytoplasm of these receptors take darker stain whereas nucleolus and chromatin material are scanty visible (Figs. 45, 50, 51).

The primary neurones are very common in occurrence in the olfactory mucosa of O. bimaculatus. Their rich concentration is observed in the angles of proximal zones of two lamellae at the point of their junction with raphe (Figs. 47, 54). The primary neurones are also observed in the distal zone where they establish synaptic contact with spindle shaped receptor cells (Fig. 46). They are having oval or rounded nucleus which takes dark stain of haematoxylin. Dendrites are eosinophilic in nature and their identity can clearly be traced out towards the interlamellar spaces (Figs. 47, 54).

The spindle shaped receptor cells (SR.) are present in the distal and proximal zones of the lamellae. They possess spindle shaped body with clear extension of axons and dendrites (Figs. 46, 47, 49, 50). They are



frequently distributed in the distal zone of lamellae where the cells are scatterly arranged. Their nuclei (NU. SR.) take dark stain and are elongated in shape. The spindle shaped receptor cell, in the distal zone of lamellae, establishes synaptic contact between its dendrite and axon of primary neurone. Hence independent extension of dendrites of these cells cannot be traced out on the peripheral surface of the lamellae. Independent axon identity and its meeting with folium olfactorium is clearly visible in this zone (Fig. 46).

#### The goblet cells:

The mucous secretory goblet cells (GC.) are commonly produced with the result of muciferous activity of supporting and basal cells in the distal zone of lamellae and lamellaeless area of the olfactory epithelium (Figs. 44, 46, 48, 53). The goblet cells are rarely present in the proximal zone of lamellae. A fully developed goblet cell is having an apical end, filled with pale droplet of mucin and slender basal end, containing compressed nucleus and small amount of darkly stained cytoplasm. The apical part of the cell has an expanded cup, called theca (TH. GC.) filled with secretory droplets. It becomes empty after discharging the mucous in to the interlamellar spaces (Figs. 48, 51, 53). The proximal or inner end is filamentous,



extending upto the basement membrane. It is difficult to observe the presence of nucleolus and chromatin material due to the higher degree of compression.

The goblet cells may be produced either by positive muciferous activity of supporting (TSC.) or by basal cells (TBC). The former is having larger while latter with smaller theca. As soon as the muciferous activity starts in the basal cells, they gradually migrate towards the periphery of the lamellae for discharging their mucous in to the interlamellar spaces. This activity is also observed in the lamellaeless area of the olfactory epithelium (Figs. 46, 48, 51, 53).

The basal cells:

The basal cells (BC.) are rounded and arranged in single to many layers in the olfactory epithelium of O. bimaculatus. They are irregularly distributed in the distal zone (Figs. 46, 51) of lamellae and they can also be observed in the supporting zone (Figs. 45, 46). The grouping of basal cells (GR. BC., Figs. 45, 50, 51) can also be seen in the mucosa. The presence of basal cells in the supporting zone indicates that they are in process of their transformation in some other cellular components, serving the purpose of repair or addition to the mucosal

Fig. 51. Longitudinal section of the anterior lamella of O. bimaculatus passing through its distal region displaying its attachment with lamellaeless area and the details of mucosa and submucosa. Magnification X 400.

Fig. 52. Horizontal section of the rosette of O. bimaculatus passing through raphe exhibiting its cellular and connective tissue details with the mode of emergence of lamellae on its either sides. Magnification X 400.

BC.	- Basal cell
BL. SI.	- Blood sinus
BM.	- Basement membrane
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
COL. CON. TI. FIB.	- Collagen connective tissue fibre
DE. LAM.	- Distal end of lamella
DE. NCI. SC.	- Distal end of nonciliated supporting cell
FBC.	- Fibroblast cell
FI. OLF.	- Folium olfactorium
GR. BC.	- Grouping of basal cells
INT. LAM. SP.	- Intralamellar space
LAM.	- Lamella
MU.	- Mucous
NCI. SC.	- Nonciliated supporting cell
NMN. FIB.	- Nonmedullated nerve fibre
PRO. LAM.	- Proximal end of lamella
RPH.	- Raphe
RR.	- Rod shaped receptor cell
TBC.	- Transitionary basal cell
TH. GC.	- Theca of goblet cell
TSC.	- Transitionary supporting cell

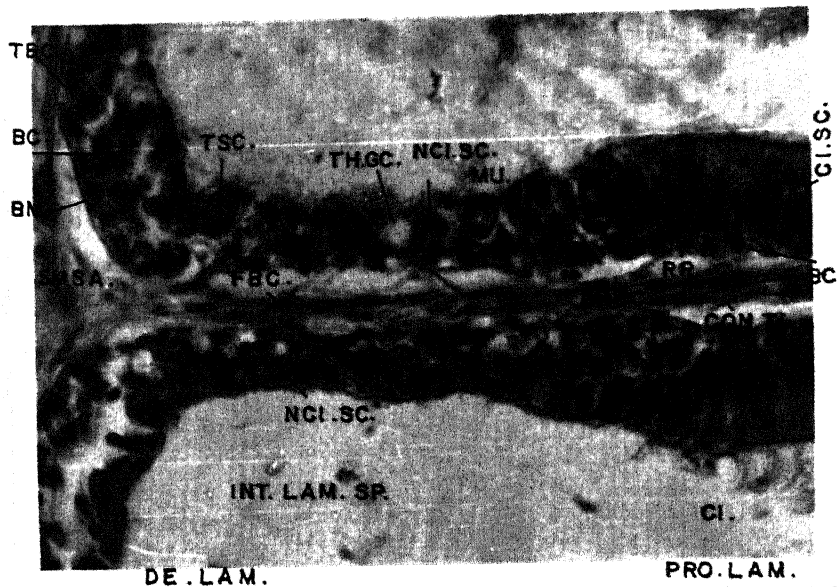


FIG. 51.



FIG. 52

Fig. 53. Longitudinal section of the lamellaeless area of O. bimaculatus displaying the discharge of mucous and extrusion of cells. Foreign material entangled in mucous is also demonstrated in this section. Magnification X 400.

Fig. 54. Transverse section of O. bimaculatus passing through the junction of two lamellae at the place of their attachment with raphe showing the details of mucosa and submucosa with special reference to the concentration of primary neurones with their dendrites. Magnification X 1000.

BC.	- Basal cell
CON. TI.	- Connective tissue
DE. SC.	- Distal end of supporting cell
DN. PN.	- Dendrite of primary neurone
EXT. C.	- Extrusion of cells
FBC.	- Fibroblast cell
FGN. MU.	- Foreign material entangled in mucous
GC.	- Goblet cell
HIS.	- Histocyte
NCI. SC.	- Nonciliated supporting cell
NU. PN.	- Nucleus of primary neurone
OCI.	- Olfactory cilia
SMSA.	- Submucosa
TBC.	- Transitional basal cell
TSC.	- Transitional supporting cell

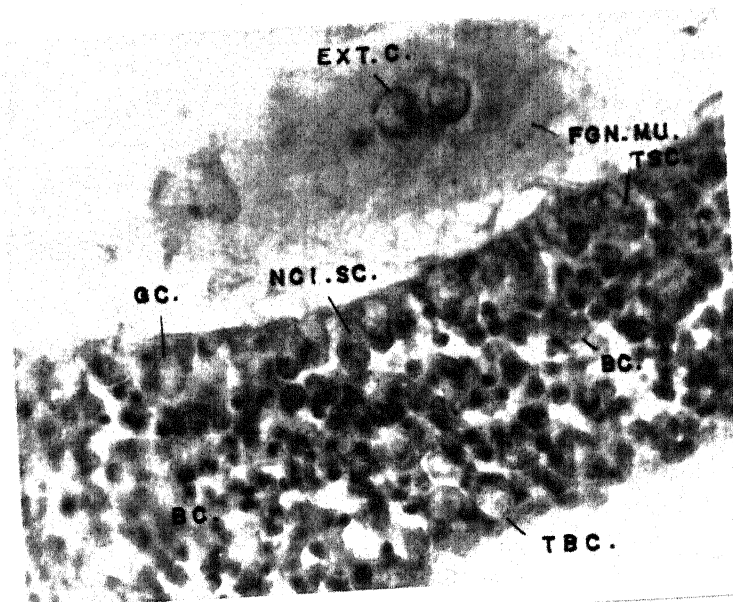


FIG. 53.

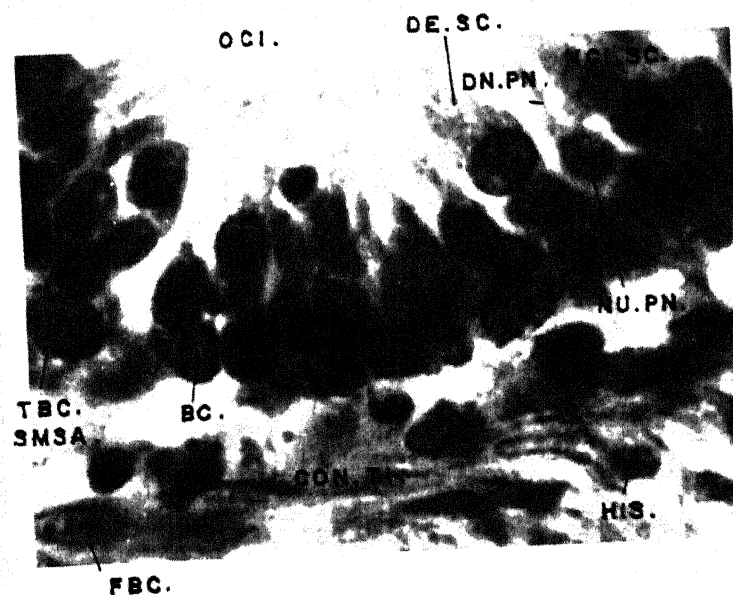


FIG. 54



elements. The basal cell in O. bimaculatus have irregular well stained nucleus with faintly visible chromatin material and nucleolus. The basal cells are found in many layers in the olfactory epithelium of lamellaeless area (Figs. 48, 53). In proximal zone of the lamellae they are present in single layer below the supporting cells (Figs. 44, 45, 47, 50) but in distal zone they are ununiformly distributed, intermingled with other cellular components (Figs. 44, 46, 51).

#### The central core or submucosa:

The central core or submucosa (SMSA.) is lined on either sides by a well defined basement membrane (BM.). It is supplied with connective tissue fibres, folium olfactorium and blood capillaries. The submucosa in the anterior lamellae is uniform and becomes somewhat more bulky in the distal zone but in posterior lamellae it becomes enormously enlarged (Fig. 43), pushing the mucosal components to a thin layer. The fibroblasts (FBC.), histiocytes (HIS) and basal (BC.) cells are commonly present in the matrix of submucosa but pigment cells are absent (Figs. 44, 45, 46, 49, 50, 54).

#### The raphe:

The raphe (RPH.) is made up of simple columnar epithelium which lies on either sides of the well demarcated



basement membrane. The columnar cells bear darkly stained nuclei, situated just above the basement membrane, in an uniform level. The elongated distal or outer limb (DE. NCI. SC.) of these cells extends upto peripheral surface of the olfactory epithelium of raphe and it is nonciliated. The proximal limb is occupied by the nucleus (NU. NCI. SC.) and cytoplasm. No other cellular components are observed in the olfactory epithelium of raphe of O. bimaculatus. The central core or submucosa of the raphe is spacious and filled with collagen connective tissue (COL. CON. TI. FIB). The nonmedullated nerve fibres are observed below the basement membrane which send their nervous supply to lamellae. The blood capillaries and their direction of supply can be seen in the raphe of O. bimaculatus. The fibroblasts, histiocytes and basal cells are also present in the connective tissue of raphe (Figs. 41, 42, 43, 52).

Fig. 55. Lateral view of the head of N. chitala.

Fig. 56. Dissection of the head of N. chitala from lateral side to show the rosette insitu.

ADNAS. H.	- Adnasal half
ANT. NAS. TEN.	- Anterior nasal tentacle
EY.	- Eye
LAM.	- Lamella
LAM. LESS AREA	- Lamellaeless area
NAS. H.	- Nasal half
OLF. CHAM.	- Olfactory chamber
POST. NAS. OP.	- Posterior nasal opening

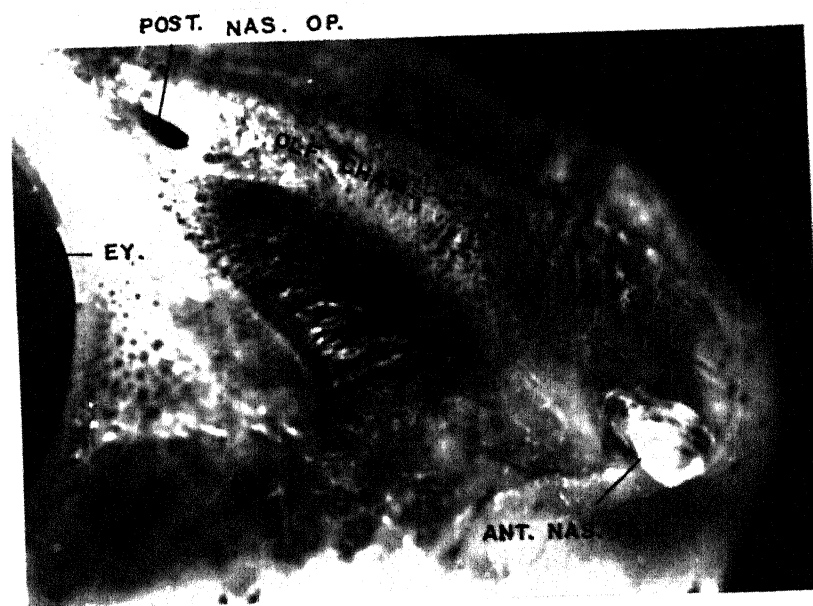


FIG. 55.

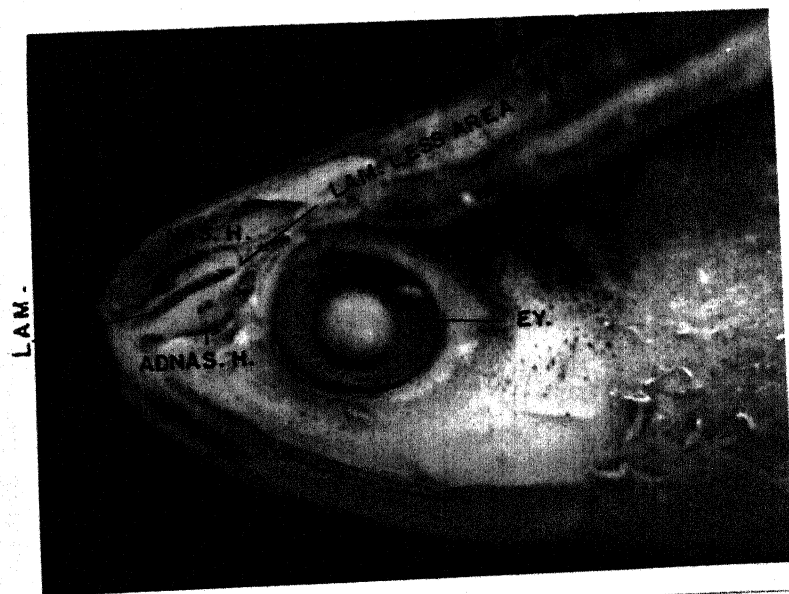


FIG. 56.

- Fig. 57A. Diagram of the lateral view of head of N. chitala.
- Fig. 57B. Magnified diagrammatic sketch of anterior and posterior nasal openings with nasal tentacle and external demarcation of olfactory chamber in N. chitala.
- Fig. 57C. Magnified sketch of the rim of anterior nasal opening of N. chitala after removing the nasal tentacle.
- Fig. 57D. Diagrammatic sketch of the rosette of N. chitala to show the circulation of water. Arrow indicating the entry and exit of course of circulation within the olfactory chamber.
- Fig. 57E. A set of 1-38 lamellae from one half of a rosette in N. chitala.

CEN. CH.	- Central channel
CONFLUENCE	- Confluence
EY.	- Eye
INT. LAM. SP.	- Interlamellar space
LAM. LESS AREA	- Lamellaeless area
LING.	- Linguiform process
NAS. TEN.	- Nasal tentacle
OLF. CHAM.	- Olfactory chamber
PER. CH.	- Peripheral channel
POST. NAS. OP.	- Posterior nasal opening
RIM.	- Rim
RPH.	- Raphe
VENT. GROOVE	- Ventral groove

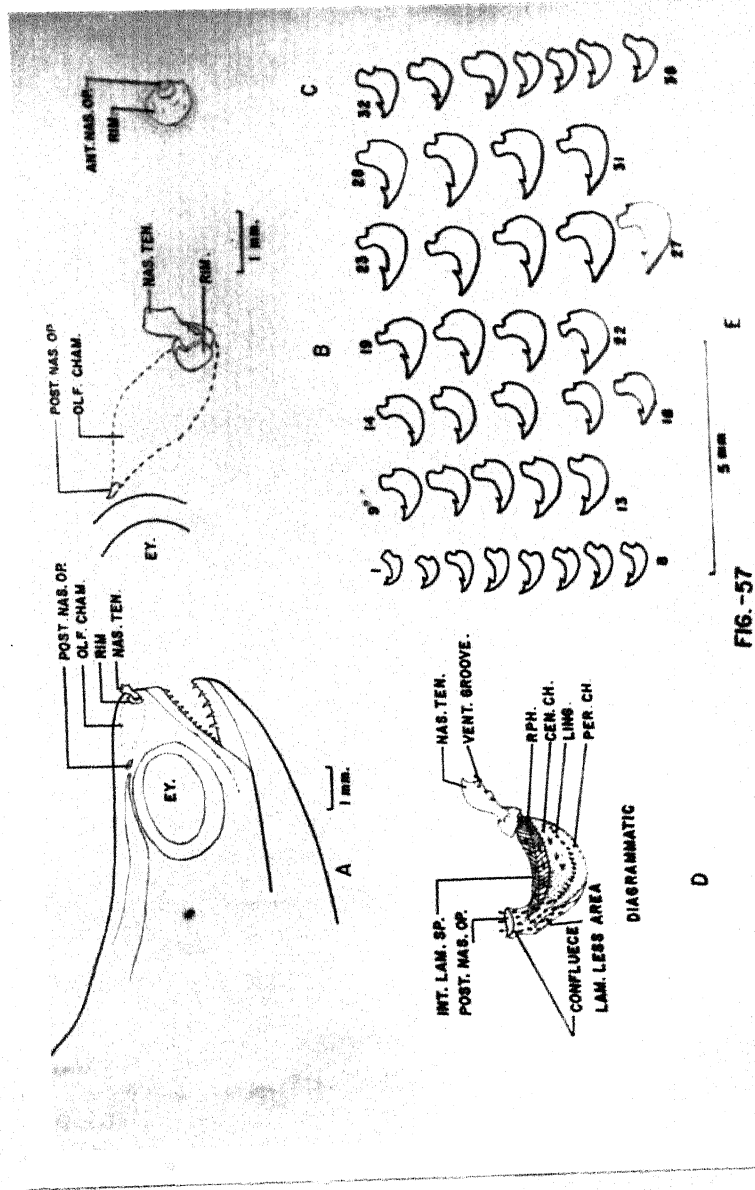


FIG. -57

Fig. 58A. Diagram of the lateral view of skull of N. chitala.

Fig. 58B. Diagram of anterior part of skull of N. chitala after removing adnasals, nasal and orbitals to show the floor of olfactory chamber.

ADNAS.	- Adnasal
DEN.	- Dentary
ECT.	- Ectopterygoid
ENT.	- Entopterygoid
ETH.	- Ethmoid
FRON.	- Frontal
LAC.	- Lacrymal
LETH.	- Lateral ethmoid
LOW. LONG. RG.	- Lower longitudinal ridge
MAX.	- Maxilla
MED. LONG. RG.	- Median longitudinal ridge
MPT.	- Metapterygoid
NAS.	- Nasal
OLF. CHAM.	- Olfactory chamber
OLF. FOR.	- Olfactory foramen
OP.	- Operculum
ORBSPH.	- Orbitosphenoid
PAS.	- Parasphenoid
PREMAX.	- Premaxilla
PREOP.	- Preoperculum
Q.	- Quadrate
UP. LONG. RG.	- Upper longitudinal ridge
2, 3, 4, 5	- Circumorbitals

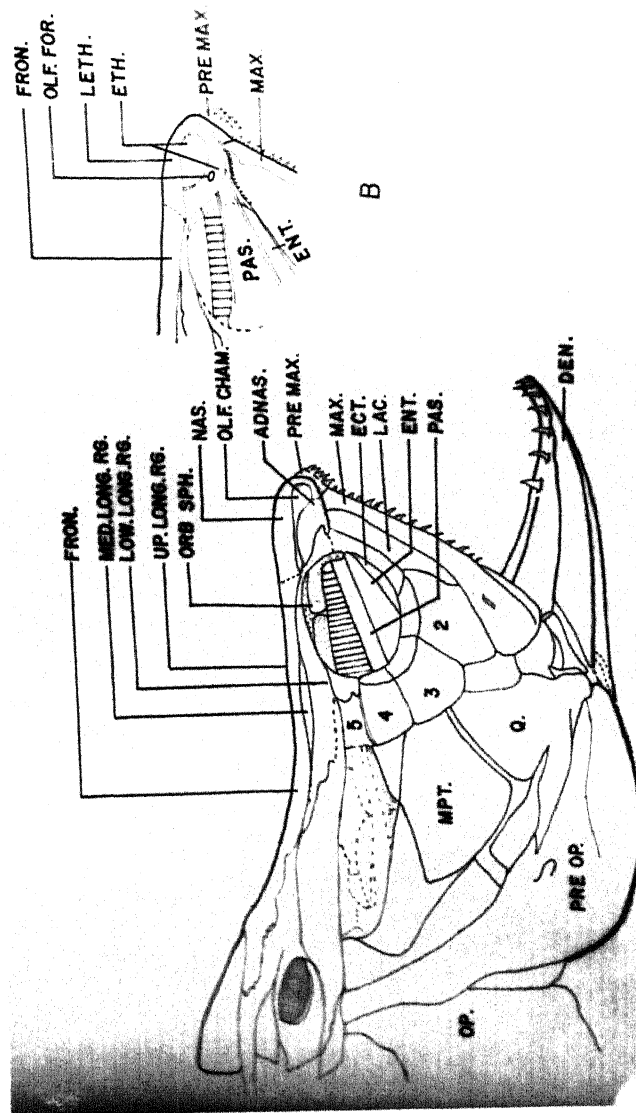


FIG.-58

Fig. 59. Diagram of the dissection of head of N. chitala from dorsal side to show the relationship of brain with the rosette.

CE.	- Cerebellum
EY.	- Eye
OLF. BL.	- Olfactory bulb
OLF. LO.	- Olfactory lobe
OLF. N.	- Olfactory nerve
OLF. TR.	- Olfactory tract
OP. LO.	- Optic lobe
RE.	- Rosette

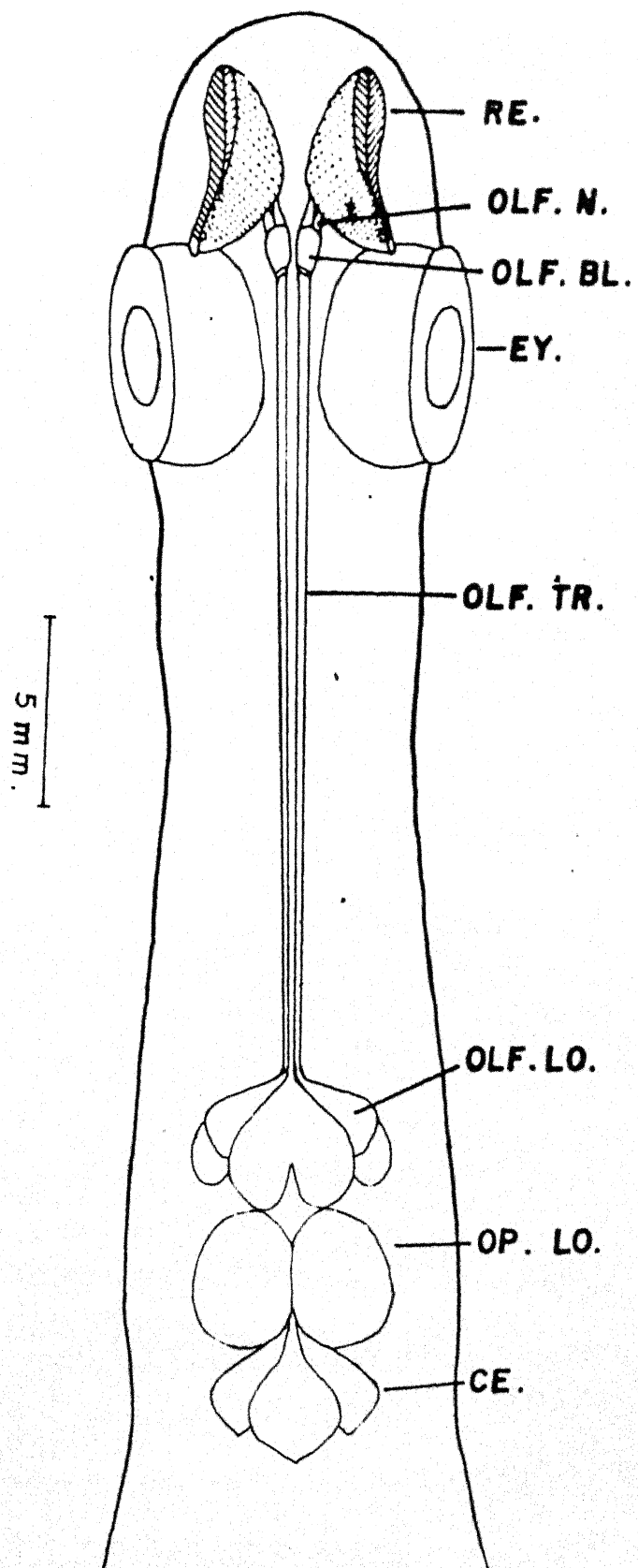


FIG. - 59

Fig. 60. Horizontal section of the rosette of N. chitala passing through few lamellae showing clear cut zonation of supporting and sensory zones. Turger and notch are also visible. Magnification X 100.

Fig. 61. Horizontal section of the rosette of N. chitala displaying the attachment of lamellae on either sides of the raphe with branched pigment cells. Magnification X 100.

BL. SI.	-	Blood sinus
CI.	-	Cilia
CON. TI.	-	Connective tissue
GC.	-	Goblet cell
INT. LAM. SP.	-	Interlamellar space
LAM.	-	Lamella
MSA.	-	Mucosa
NT.	-	Notch
PIG.	-	Pigment cell
RPH.	-	Raphe
SC. Z.	-	Supporting zone
SEN. Z.	-	Sensory zone
SMSA.	-	Submucosa
TUR.	-	Turger

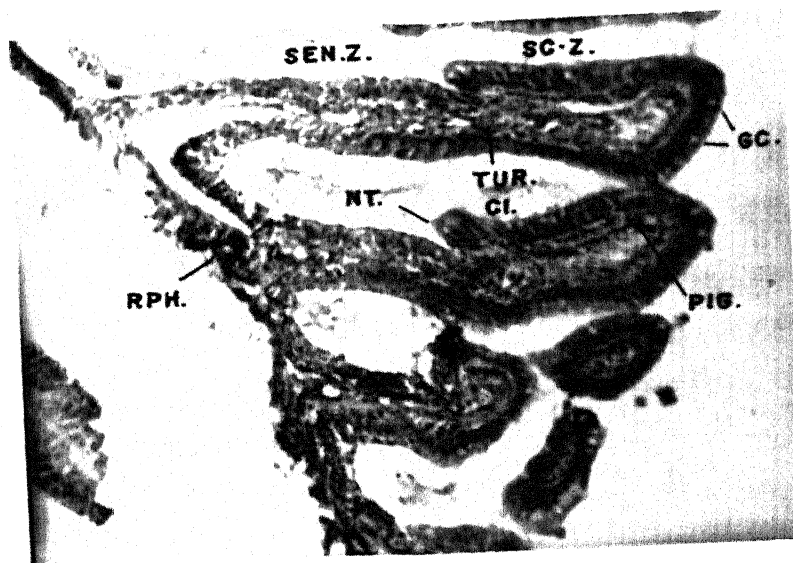


FIG. 60.

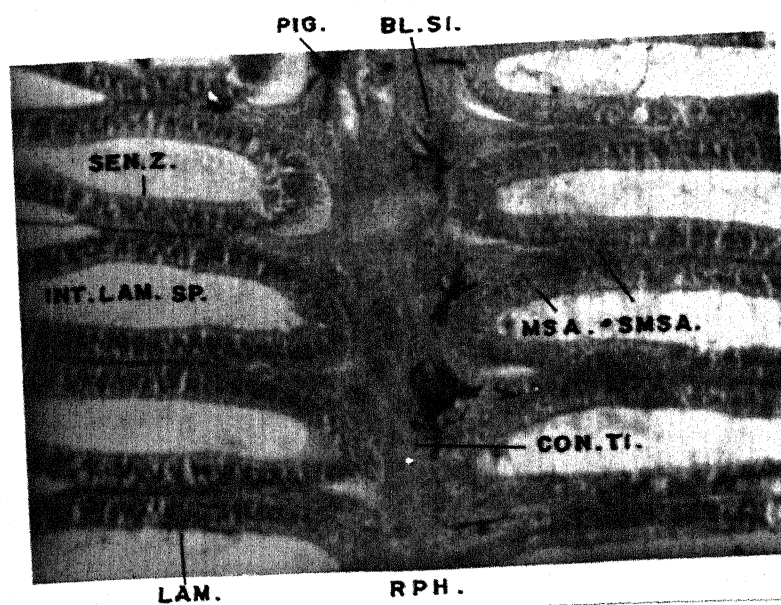


FIG. 61.

Fig. 62. Longitudinal section of the middle region of lamella of N. chitala showing dense ciliation and cellular composition. Magnification X 400.

Fig. 63. Longitudinal section of distal region of supporting zone of the lamella of N. chitala displaying heavy ciliation, pigmentation, turgor supply and muciferous activity. Magnification X 400.

BC.	- Basal cell
BCP.	- Blood capillary
BM.	- Basement membrane
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
DE. CI. SC.	- Distal end of ciliated s supporting cell
FI. OLF.	- Folium olfactorium
GC.	- Goblet cell
GR. BC.	- Grouping of basal cell
INT. LAM. SP.	- Interlamellar space
MU.	- Mucous
NT.	- Notch
NU. CI. SC.	- Nucleus of ciliated supporting cell
PIG.	- Pigment cell
TUR.	- Turgor

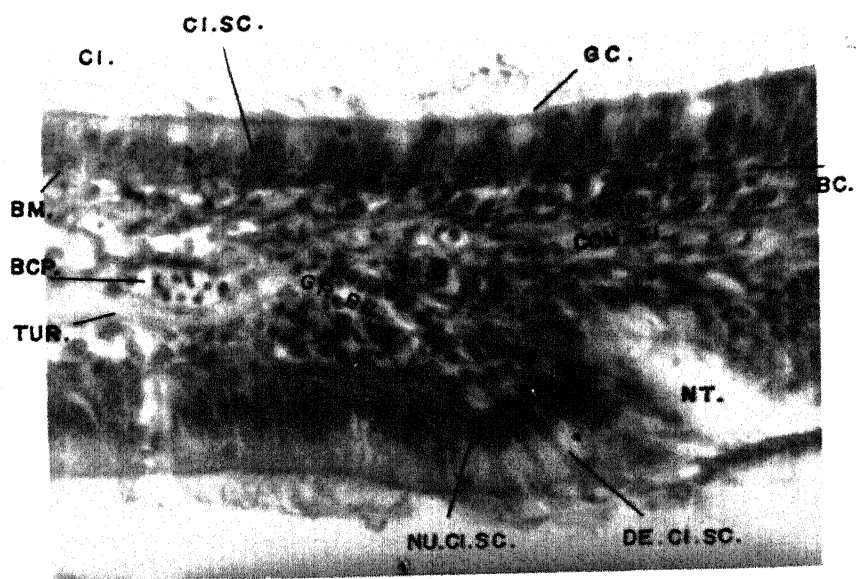


FIG. 62.

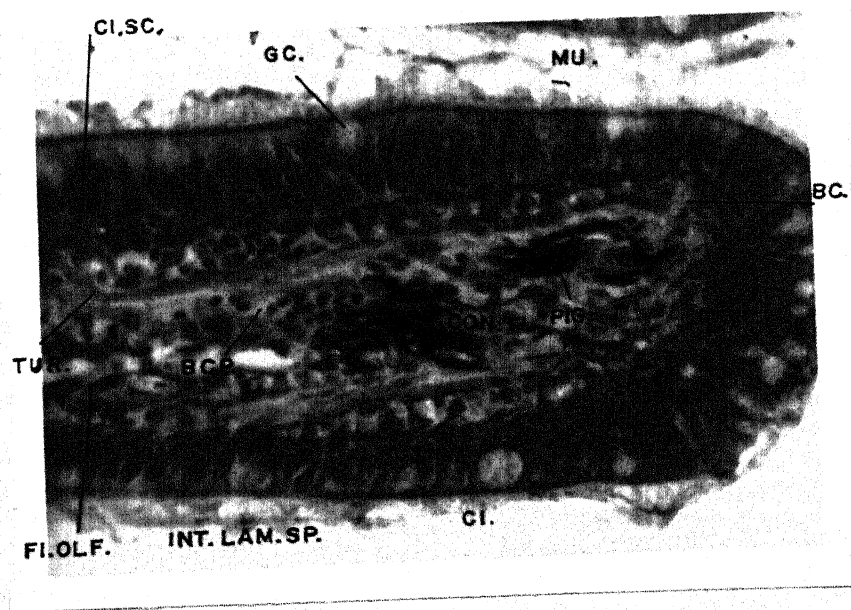


FIG. 63

MORPHOLOGICAL OBSERVATIONS OF OLFACTORY ORGAN  
OF NOTOPTERUS CHITALA (HAMILTON)

The olfactory organs in N. chitala are comprised of a pair of olfactory chambers (OLF. CHAM.) lying slightly projected over the maxilla and extend upto the anterior extremities of eye orbits at the point of initiation of lower and upper ridges (LOW. LONG. RG., UP. LONG. RG.) of frontal bone (Figs. 57A, 58). Each olfactory chamber is anteriorly narrow and broadens posteriorly, occupying a large area which is richly supplied with chromatophores. Each olfactory chamber is communicated outside by a pair of nasal openings. The anterior nasal opening (ANT. NAS. OP.) is rounded and thickly rimmed, situated lateromedially on the roof of the skull in the anterior most part of the head. The rim of anterior nasal opening is provided with a forwardly directed and ventrally grooved nasal tentacle (NAS. TEN.), helping in deflecting the water current to the anterior nasal opening of the fish during its forward movement. The posterior nasal opening (POST. NAS. OP.), situated on the general surface of the head is oval and in confluence with the posterior elevated extension of olfactory rosette. It is nonvalvular opening, lying on the anterodorsal margin of the eye orbit (Figs. 57A, 57B, 57C). It is based on the posterior extremities of nasal and adnasal bones. Posteriorly this opening is guarded by

the anterior extremities of lower and upper longitudinal ridges of frontal (Fig. 58).

In a fish of 631 mm total length, the anterior and posterior nasal openings are situated at a distance of 9.945 mm. The anterior nasal opening is 0.468 mm in diameter and equipped with a forwardly directed nasal tentacle of 2.047 mm in height. The posterior nasal opening is 1.404 x 0.643 mm in size.

Each olfactory chamber is completely occupied by an elongated and boat shaped olfactory rosette (RE., Figs. 56, 94) which bears ventral convex and dorsal concave surfaces. The former is pigmented (PIG.) and thickly covered by fibrous connective tissue but latter is provided with free dorsal ends of the olfactory lamellae (LAM.) which maintain interlamellar spaces (INT. LAM. SP.) in between them (Figs. 60, 61, 64). The rosette has a posterior broader end and its elevated margins are in confluence with the posterior nasal opening. It is composed of two halves by virtue of their respective position in relation to nasal and adnasal bones. A raphe (RPH.) runs anteroposteriorly in each rosette and lamellae radiate from its either sides. The succession of attachment of lamellae, in each half of the olfactory rosette, is in such a manner that larger ones are present in the poster-medial part whereas the ends are provided with smaller ones.

The anterior most lamella is smaller as compared to the posteriormost (Figs. 56, 94). The chromatophores (pigment cells) are seen in the raphe and distal parts of the lamellae (Figs. 61, 63, 64, 94).

The olfactory lamellae (LAM.) in N. chitala are plough shaped, bearing dorsal concave and ventral convex surfaces. The latter is attached with the floor of olfactory chamber by fibrous connective tissue while the former is free. In between the two lamellae a conspicuous interlamellar space is present to facilitate the sufficient dipping of all the lamellae by circulating water. The lamellae are provided with narrow proximal, pointed and curved distal ends. The medial part of each lamella is broad and linguiform process (LING.) is present distally on the dorsal surface (Fig. 57E). The linguiform processes of all the lamellae take a shape of curtain, dividing the olfactory chamber in to central (CEN. CH.) and peripheral (PER. CH.) channels. The posteriormost part of the rosette is devoid of lamellae and its elevated margins are in confluence with posterior nasal opening, taking a shape of extra olfactory nasal sac which helps in maintaining the continuity of water in the olfactory chamber (Fig. 94). The movement of cilia (CI., Figs. 62, 63, 67, 68) of olfactory epithelium invites the water into the olfactory chamber through anterior nasal opening and ultimately expelled out from the posterior.

The olfactory rosette is lodged in the olfactory chamber in ethmoidal region and is attached with the surrounding bony components by fibrous connective tissue. The floor of olfactory chamber is mainly made up of grooved lateral ethmoid (LETH.). The ethmoidal ridge (ETH. RG.) separates the olfactory chambers of either sides and ethmoid (ETH.) contributes in the formation of one third mediolateral part of the floor of olfactory chamber. The nasal (NAS.) and adnasal (ADNAS.) bones form the margins of the olfactory chamber. The left margin of the right olfactory chamber and the right margin of the left olfactory chamber are bounded by nasal. The adnasal erects opposite to the nasal in each olfactory chamber. Both nasal and adnasal terminate posteriorly to form the posterior nasal opening (Fig. 58).

The lateral ethmoid terminates posteriorly into a narrow process and articulates with the orbitosphenoid (ORBSPH.). The olfactory bulb (OLF. BL., Fig. 59) lies in a groove, present at the place of articulation of lateral ethmoid and orbitosphenoid. The lateral ethmoid bears an opening for the optthalmicus profundus nerve. The olfactory tract (OLF. TR., Fig. 59) runs throughout the length of orbitosphenoid and plausphenoid (PLAUSPH.). The olfactory chamber is anteriorly supported by premaxilla (PREMAX.) and posteriorly by lower and upper longitudinal ridges (LOW.

LONG. RG., UP. LONG. RG.) of frontal. Ventrolaterally and dorsolaterally the olfactory chambers are supported by maxilla (MAX.) and lacrymal (LAC.) bones respectively (Fig. 58).

The dissection of the head from its dorsal side shows anatomical relationship of the brain to the olfactory rosette. The olfactory bulbs are rounded and situated close to the posterior ends of the olfactory rosettes. The paired olfactory tracts (OLF. TR.) are elongated and originate from the anteriormost part of the telencephalon and terminate to the olfactory bulbs. Each olfactory bulb give rises to a pair of the olfactory nerves, extending posteroanteriorly on the ventral surface of the rosette. The optic (OP. LO.) and olfactory (OLF. LO.) lobes are almost equally developed (Fig. 59).

#### Ecological coefficient:

Already established methods were adopted for calculating the ecological coefficient in N. chitala for illustrating the appropriate sensitivity of olfactory and optic faculties. Five fishes of different sizes ranging from 223 to 631 mm were selected for calculating the ecological coefficient. The number of lamellae and length of the brain increase successively with the increasing size of the fish. The length of mesencephalon ranges from

Table 3: Ecological coefficient of Notopterus chitala

Sl. No.	Total length (mm)	Number of lamellae Rosette		Total length of brain (mm)	Length of mesencephalon (mm)	Length of telencephalon (mm)	Ecological coefficient (Through lobes of brain) Length of telencephalon x 100 Length of mesencephalon	Retinal area of both eyes (mm <sup>2</sup> )	Olfactory area of both rosette (mm <sup>2</sup> )	Ecological coefficient (Through area) Olfactory area x 100 Retinal area
		Right	Left							
1	223	76	76	14.795	4.680	4.972	106.239	55.916	1005.369	1797.998
2	278	92	92	20.000	4.693	4.994	106.413	108.382	2007.234	1851.999
3	280	92	92	20.040	4.819	5.000	103.755	109.900	2189.208	1992.000
4	303	96	96	21.500	4.914	5.031	102.380	146.356	2944.682	2011.999
5	631	152	152	28.000	6.201	6.435	103.773	194.050	3865.476	1992.000
Average				20.867	5.061	5.286	104.512	122.920	2402.393	1929.199

83



4.680 to 6.201 mm and that of telencephalon from 4.972 to 6.435 mm, revealing ecological coefficient 104.512 per cent as an average which indicates that the olfactory and optic faculties are almost equally developed (Table 3).

The area of two retinae ranges from 55.916 mm<sup>2</sup> to 194.05 mm<sup>2</sup> and that of two rosettes 1005.369 to 3865.476 mm<sup>2</sup>. The average ecological coefficient calculated in five fishes, stands 1929.199 per cent, demonstrating tremendously developed olfactory faculty (Table 3). The development of mesencephalon is also considerably high and because of this fact an amountable development of optic faculty cannot be denied. N. chitala is a bottom feeder and found between the bottom bushes and becomes more active in night. This fact correlates its habit of more dependent on olfactory faculty in discharging the activities like feeding, schooling defence and courtship. However, optic faculty also plays supplementary role, making the fish more efficient.

The route of water circulation through the olfactory chamber of N. chitala:

The extra olfactory nasal sac is subjected to a constant change in its volume with the result of jaws and respiratory movements. In addition to speedy forward movement of fish synchronously with nasal tentacular



erection in forward direction, the water current is invited through the anterior nasal opening via ventral groove of nasal tentacle (Figs. 57B, 57C, 57D). After its reception, the water is circulated in the olfactory chamber through central and peripheral channels and ultimately stored in the extra olfactory nasal sac, the posteriormost lamellaeless area of the olfactory rosette. The extra olfactory nasal sac (lamellaeless area) increases the capacity of accommodating the water in the olfactory chamber so that olfactory lamellae may be properly bathed with ingoing water current. The lamellar ciliation (Figs. 62, 63, 67, 68) causes the circulation of water in the olfactory chamber and the same is expelled out through the posterior nasal opening.

100

HISTOLOGICAL OBSERVATIONS OF OLFACTORY ORGAN OF  
NOTOPTERUS CHITALA (HAMILTON)

Each olfactory rosette of N. chitala bears numerous lamellae arranged transversely on either sides of rostrocaudally elongated raphe (RPH., Figs. 56, 61, 94). Each lamella (LAM.) is constituted of central core or submucosa (SMSA.) lined on both the sides by the cellular components of mucosa (MSA.). The distal surface of all the lamellae is uniform and no secondary lamellae or microformations are observed on its surface except a notch (NT., Figs. 60, 62, 65) in between the supporting (SC.Z.) and sensory (SEN. Z.) zones. The central core is richly supplied with blood capillaries (BCP., Figs. 62, 63) and pigment cells (PIG., Figs. 60, 62, 63, 66) with thick bundles of connective tissue fibres (CON. TI. FIB.) forming a support to enormously elongated lamella on both the sides of raphe (Figs. 60, 61, 64, 65, 66). This formation of connective tissue bundles takes a shape of well formed turgor (TUR.) which is centralized in the middle zone of lamella at the level of notch, supplying its branches upto terminal end of the lamella (Figs. 60, 62, 63, 65, 66). The cellular components, in the lamellae of N. chitala, are supporting cells (SC.), receptor cells (RC.), goblet cells (GC.) and basal cells (BC.).



The distribution of above cellular components is in a peculiar fashion, showing clear cut zonation of supporting (SC. Z.) and sensory (SEN. Z.) zones in a lamella (Fig. 60). The goblet cells are absent in the sensory zone but richly present in the supporting one. The branched pigment cells (PIG.) are commonly distributed in the submucosa of raphe and supporting zone of the lamellae (Figs. 60, 61, 63, 64, 65, 68). On the basis of cellular arrangement and zonation, the lamella is divided into proximal (PRO. LAM.) and distal (DE. LAM.) regions.

The proximal region is restricted on either sides of the raphe upto the middle region of the rosette. It is purely sensory zone supplied with receptor and nonciliated supporting cells. The sensory zone is lined by stratified cuboidal epithelium. The central core or submucosa is comparatively narrow and consists of areolar connective tissue (ARE. CON. TI.). This region is totally devoid of goblet cells, pigment cells and ciliation (Figs. 60, 61, 64, 69, 70, 71).

The distal region (DE. LAM.) extends from the middle part of rosette to the lateral wall of the olfactory chamber. It comprises of ciliated columnar epithelium which is purely nutritive and supporting in nature. The broad central core is richly supplied with branched pigment



cells and thick bundles of connective tissue fibres (CON. II. FIB.). It also exhibits variation in its broadening. The blood supply and connective tissue bundles are clearly visible in this zone (Figs. 60, 62, 63, 65, 66, 67, 68).

#### The supporting cells:

The supporting cells can be distinguished into two main types: the nonciliated supporting cells (NCI. SC.) and ciliated supporting cells (CI. SC.). The former are without cilia and restricted in the sensory zone of mucosa. They are alternately situated among the receptor cells with oval nucleus and short body. The nucleus (NU. NCI. SC.) in these cells takes dark stain of haematoxylin and can be clearly observed. The chromatin material and nucleolus are faintly visible. The distal limb of supporting cell (DE. NCI. SC.) is short but shows clear appearance among the dendrites of receptor cells. It bears homogenous cytoplasm which takes lighter stain as compared to the surrounding cellular components. The proximal limb of supporting cell is inconspicuous and is not clearly traceable (Figs. 69, 70, 71).

The ciliated supporting cells (CI. SC.) are columnar and exceptionally tall, contributing the major bulk of supporting zone of the lamella in the distal half of the rosette. They are arranged perpendicularly to the

Fig. 64. Horizontal section of the rosette of N. chitala passing through raphe, exhibiting its detailed cellular and connective tissue composition with the mode of attachment of lamellae on its either sides. Magnification X 400.

Fig. 65. Longitudinal section of middle region of the lamella of N. chitala displaying turger and its supply for strengthening the lamella. Magnification X 400.

ARE.	- Areolae
BC.	- Basal cell
BL. SI.	- Blood sinus
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
COL. CON. TI. FIB.	- Collagen connective tissue fibre
CON. TI.	- Connective tissue
DE. LAM.	- Distal end of lamella
FI. OLF.	- Folium olfactorium
GC.	- Goblet cell
NMN. FIB.	- Nonmedullated nerve fibre
NT.	- Notch
NU. SC.	- Nucleus of supporting cell
PIG.	- Pigment cell
TUR.	- Turger



FIG. 64.

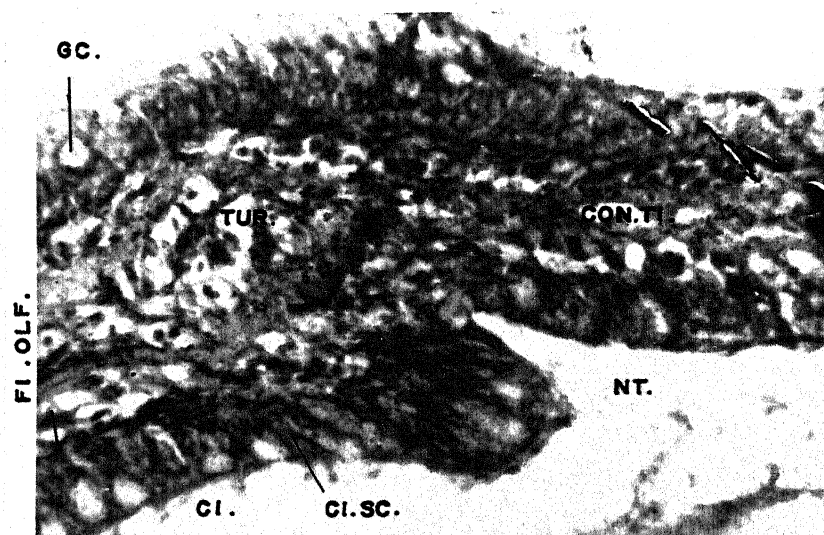


FIG. 65.

Fig. 66. Longitudinal section of the lamella of N. chitala passing through its distal end displaying the supply of turger and pigment cell. Magnification X 400.

Fig. 67. Transverse section of the lamella of N. chitala passing through the supporting zone, exhibiting the details of cellular elements in submucosa and mucosa. Magnification X 1000.

BC.	- Basal cell
BC. Z.	- Basal zone
CI.	- Cilia
CON. TI.	- Connective tissue
DE. CI. SC.	- Distal end of ciliated supporting cell
FBC.	- Fibroblast cell
HIS.	- Histiocyte
MU.	- Mucous
NU. BC.	- Nucleus of basal cell
NU. CI. SC.	- Nucleus of ciliated supporting cell
NU. GC.	- Nucleus of goblet cell
PIG.	- Pigment cell
TH. GC.	- Theca of goblet cell
TUR.	- Turger

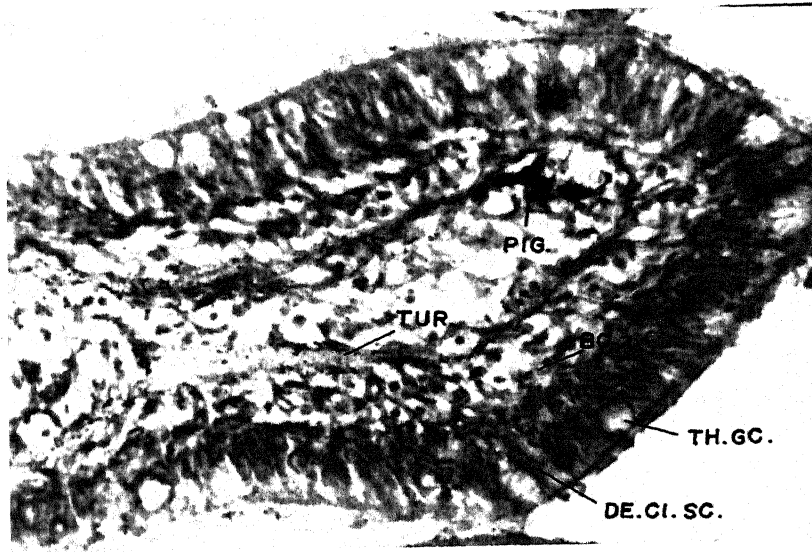


FIG. 66.

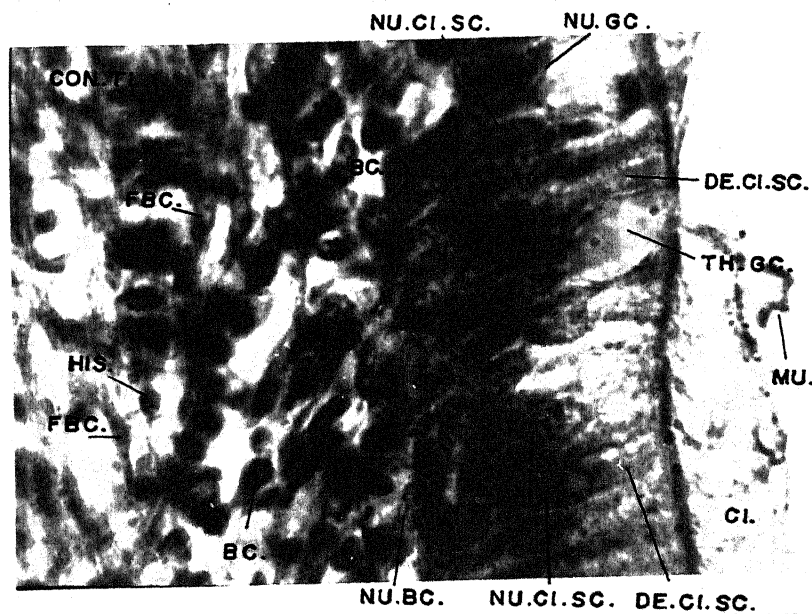


FIG. 67.



basement membrane and are heavily ciliated. The ciliated supporting cell is made up of two limbs - an inner or proximal (PRO. CI. SC.) and outer or distal (DE. CI. SC.). The former is short and thick, extending upto the basal zone while the latter is elongated and reaching upto the peripheral surface of the lamella. It ends on the peripheral surface by an expanded tip which bears many elongated cilia (CI.). The ciliation of all such supporting cells projects in the interlamellar space forming clusters and their direction of synchronous beating can be seen in the microtomical sections (Figs. 62, 63, 67, 68). The proximal and distal limbs of ciliated supporting cells have clear and homogenous cytoplasm. The distal limb takes darker stain as compared to the proximal one. The ciliated supporting cells exhibit positive muciferous activity, with the result supporting zone is richly supplied with elongated goblet cells. The muciferous activity becomes more prominent in the terminal tips of the lamellae. The mucous discharges from the goblet cells becomes entangled with clusters of cilia which can powerfully create unidirectional ciliary movement.

The distal tips of ciliated supporting cells bear basal granules on which cilia are implanted. The nucleus of ciliated supporting cell is oval in shape and situated at different levels in the mucosa. The chromatin



material and nucleolus are clearly visible. The ciliated supporting cells are densely packed having their nuclei at different levels. The goblet cells present in the supporting zone create space among them after discharging the mucous (Figs. 62, 63, 65, 66, 67, 68).

#### The receptor cells:

On the basis of the shape of nucleus and their position in the olfactory epithelium, the receptor cells can be distinguished into primary (PN.) and secondary (SR.) types. The primary ones are confined in the sensory zone of the olfactory lamella and invariably partitioned from one another by nonciliated supporting cells (NCI. SC.). The accumulation of receptor cells is not observed anywhere in the olfactory epithelium of N. chitala. The primary receptor cell bears prominent cell body containing more or less spherical nucleus (NU. PN.). The chromatin material is distributed in the karyoplasm. It takes darker stain of haematoxylin as compared to the surrounding cellular components (Figs. 69, 70, 71).

The axon of primary receptor cell is not traceable as an independent element because it establishes synaptic contact (SY.) with the dendrite of secondary receptor. The distal and outer margin of primary receptor cell give rises a dendrite (DN. PN.) whose tip may projects in the inter-



lamellar spaces directly or in some other forms. The distal tip of dendrite of these receptors is in the shape of olfactory vesicle (OV.). The projection of olfactory vesicle in the interlamellar spaces is of varying degree but at some places they form well marked projection either in the form of microvilli (MV.) or olfactory cilia (OLF. CI.). The dendrite of primary receptor cell attains darker stain as compared to the surrounding cellular components (Figs. 69, 70, 71).

The spherical nuclei of primary receptor cells form an ill defined zone among the nuclei of nonciliated supporting cells. The length of dendrite depends upon the placement of these receptor cells in the mucosa of olfactory epithelium. Consequently, the deeply situated primary receptor cells having elongated dendrites as compared to those present in the peripheral surface of mucosa.

The secondary receptor cells (SR.) possess somewhat slender body with scanty cytoplasm, surrounding the elongated and oval nucleus (NU. SR.). The nucleus stains less intensely with haematoxylin as compared to the nucleus of primary receptor cell. It has a conspicuous nucleolus with scattered chromatin material in karyoplasm. A thin proximal process of axon (AX. SR.) extends upto the basement membrane where they join to form folium olfactorium (FI. OLF.). The dendrites (DN. SR.) are not seen extending



upto the peripheral surface but make synaptic contacts (SY.) with axons of primary receptor cells. It is difficult to trace the synaptic contact between primary and secondary receptor cells but however, few synaptic contacts are clearly visible due to careful sectioning and staining of the material. The presence of these receptor cells below the primary ones demonstrate their nomenclature as secondary receptors but they are identical to spindle shaped receptor cells (Figs. 60, 70, 71).

#### The goblet cells:

The goblet cells (GC.) are confined in the supporting zone of lamella, intermingled with the ciliated supporting cells. No muciferous activity is observed in the basal zone. This indicates that some of the supporting cells, having positive muciferous activity, give rise to goblet cells. The theca of these goblet cells is elongated and of the size of ciliated supporting cell. The nucleus is well compressed with darkly stained chromatin material. The proximal limb of goblet cell is not traceable underneath the supporting zone because of the presence of compact basal cells. The muciferous activity of supporting cells can clearly be demonstrated as the goblet cells of different formative stages can be seen in the supporting zone of N. chitala. The theca of goblet cells may be sunken deep

Fig. 68. Transverse section of the lamella of N. chitala passing through the distal end of supporting zone showing clusters of cilia, turger supply and other cellular components of mucosa and submucosa. Magnification X 1000.

Fig. 69. Transverse section of the lamella of N. chitala passing through sensory zone showing synaptic contact, olfactory vesicle, primary neurone and non ciliated supporting cells. Magnification X 1000.

AX.	- Azon
BC.	- Basal cell
CI.	- Cilia
CON. TI.	- Connective tissue
DE. CI. SC.	- Distal end of ciliated supporting cell
DN.	- Dendrite
FBC.	- Fibroblast cell
HIS.	- Histiocyte
NCI. SC.	- Nonciliated supporting cell
NU. CI. SC.	- Nucleus of ciliated supporting cell
NU. GC.	- Nucleus of goblet cell
NU. SR.	- Nucleus of secondary receptor
OV.	- Olfactory vesicle
PIG.	- Pigment cell
PN.	- Primary neurone
SMSA.	- Submucosa
SR.	- Spindle shaped receptor cell
SY.	- Synaptic contact
TH. GC.	- Theca of goblet cell
TUR.	- Turger

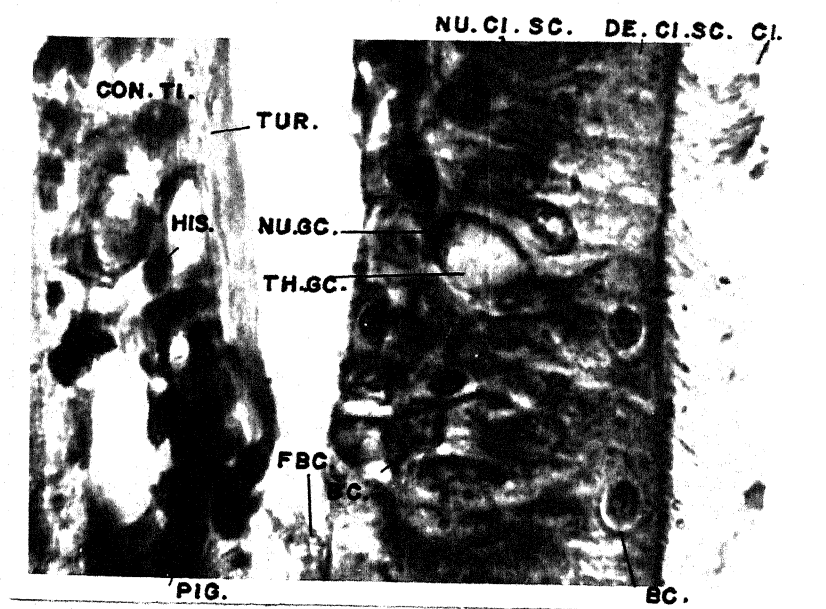


FIG. 68.

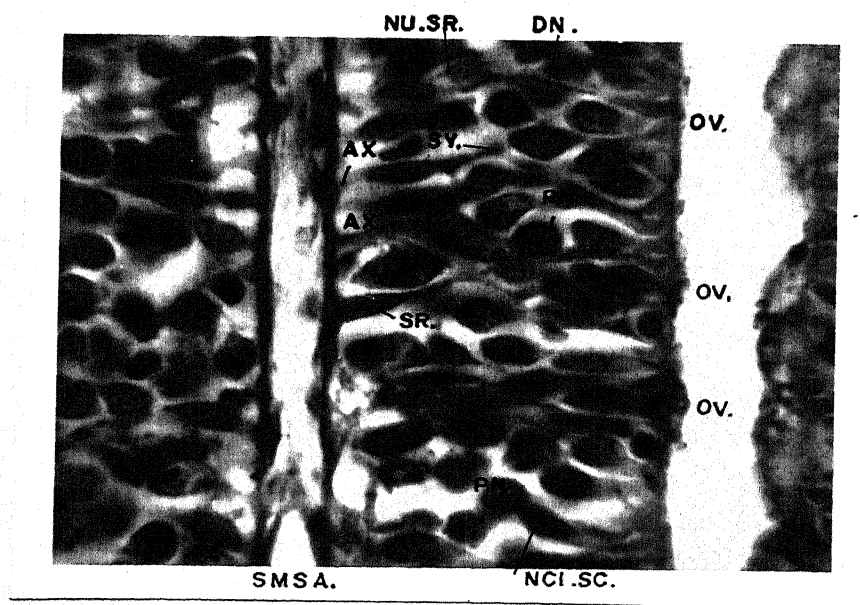


FIG. 69.

Fig. 70. Transverse section of the lamella of N. chitala passing through sensory zone showing perfect cellular picture of mucosa and submucosa with special reference to olfactory cilia, olfactory vesicle, microvilli and elongated dendrites of secondary receptors. Magnification X 1000.

Fig. 71. Transverse section of the lamella of N. chitala passing through sensory zone showing microvilli, olfactory vesicle, olfactory cilia, and axons and dendrites of receptor cells. Magnification X 1000.

AX. SR.	- Axon of secondary receptor
FI. OLF.	- Folium olfactorium
INT. LAM. SP.	- Interlamellar space
MV.	- Microvilli
NCI. SC.	- Nonciliated supporting cell
NU. BC.	- Nucleus of basal cell
NU. NCI. SC.	- Nucleus of nonciliated supporting cell
NU. PN.	- Nucleus of primary receptor
NU. SR.	- Nucleus of secondary receptor
OCI.	- Olfactory cilia
OV.	- Olfactory vesicle
PN.	- Primary receptor
SMSA.	- Submucosa

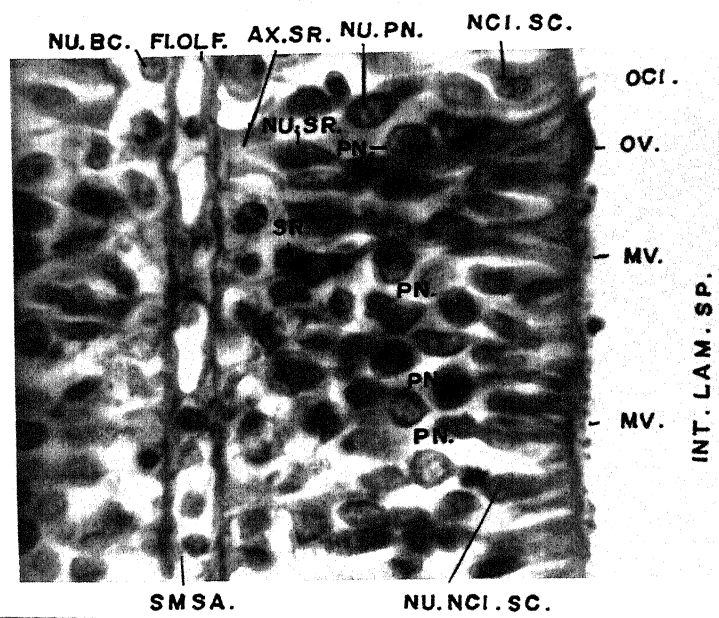


FIG. 70.

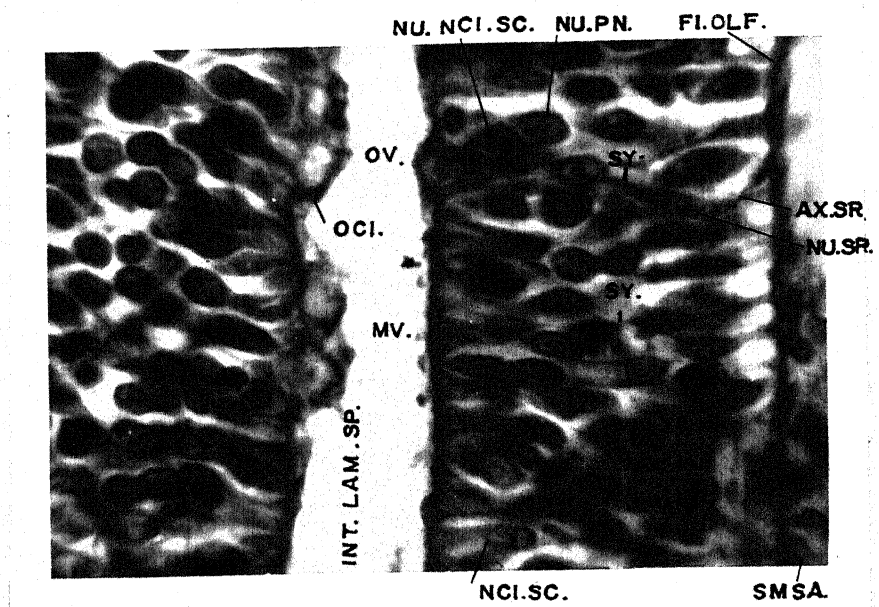


FIG. 71.



in the mucosa or may be situated on the periphery among the ciliated supporting cells (Figs. 62, 63, 65, 66, 67).

#### The basal cells:

The basal cells (BC.) are uniformly distributed in the supporting zone of lamella above the basement membrane (BM.). The grouping of basal cells (GR. BC.) can also be occasionally observed in this zone which indicates their preparation in the formation of some other cellular components of olfactory mucosa. The nucleus of basal cell (NU. BC.) is rounded with clearly visible chromatin material and decentric nucleolus. In the sensory zone, the distribution of basal cells becomes ununiform and they may be seen in an irregular fashion, forming single to many layers thick basal zone (Figs. 69, 70, 71). The submucosa is also richly supplied with basal cells. The occasional migration of basal cells can be observed in the supporting zone (Fig. 68) or elsewhere, indicating that they are in the process of transformation in other cellular components according to the need of olfactory epithelium.

#### The central core or submucosa:

On the basis of zonation in the olfactory lamella of N. chitara, the central core or submucosa is seen clearly



divisible into proximal and distal zones. The former is narrow and constricted (Figs. 60, 69, 70, 71) whereas the latter is broad and expanded (Figs. 60, 62, 63, 65, 66). The central core or submucosa of both the zones is lined with well demarcated basement membrane. The sensory zone of olfactory epithelium is lined with areolar connective tissue fibres while the supporting zone with bundles of collagen connective tissue fibres (COL. CON. TI. FIB.). Both these connective tissue fibres join each other in the middle of all the lamellae at the level of notch. The turgor formation takes place in this region as the connective tissues are aggregated and provide support to the lamellae. Besides this the central core of supporting zone is supplied with blood capillaries (BCP.), branched pigment cells (PIG.) branched fibroblast cells (FBC.), histocytes (HIS) and areolae (ARE.). The central core of sensory zone is devoid of pigment cells and having thin supply of connective tissue. The folium olfactorium (FI. OLF.) extends below the basement membrane and joins non-mendullated nerve fibres (NMN. FIB.) in the supporting zone. The pigment cells are observed concentrated around the blood capillaries both in supporting zone as well as in raphe (Figs. 63, 64, 66, 67, 68, 70, 71).

#### The raphe:

The raphe is made up of thick nonciliated columnar



epithelium devoid of sensory cells and having enormously developed central core or submucosa (SMSA., Figs. 61, 64). The epithelial lining of central core or submucosa is separated by a well demarcated basement membrane. The basal zone of raphe in N. chitala occupies a broad area limiting three to four layers of basal cells, while the supporting cells are single layer thick, made up of short nonciliated cells.

The central core or submucosa is densely supplied with collagen connective tissue fibres (COL. CON. TI. FIB.) intermingled with areolar connective tissue fibres. Rich distribution of branched pigment cells, fibroblasts, histiocytes and basal cells is observed in the ground substance (matrix) of the raphe. The nonmedullated nerve fibres extend along the basement membrane which finally join to the medullated nerve fibres of the olfactory nerve. In the centre frequent presence of areolae is observed which remain surrounded by areolar connective tissue fibres. The blood supply is present in the raphe, and the branches of blood capillaries are supplied to all the lamellae (Figs. 61, 64).

Fig. 72. Lateral view of the head of O. bacaila.

Fig. 73. Dissection of the head of O. bacaila  
from lateral side to show the rosette  
insitu.

ANT. NAS. OP.	- Anterior nasal opening
ANT. NAS. TUBE	- Anterior nasal tube
ETH. H.	- Ethmoidal half
EY.	- Eye
LAC. H.	- Lacrymal half
LAM.	- Lamella
LAM. LESS AREA	- Lamellaeless area
NAS. FLAP	- Nasal flap
POST. NAS. OP.	- Posterior nasal opening
RPH.	- Raphe

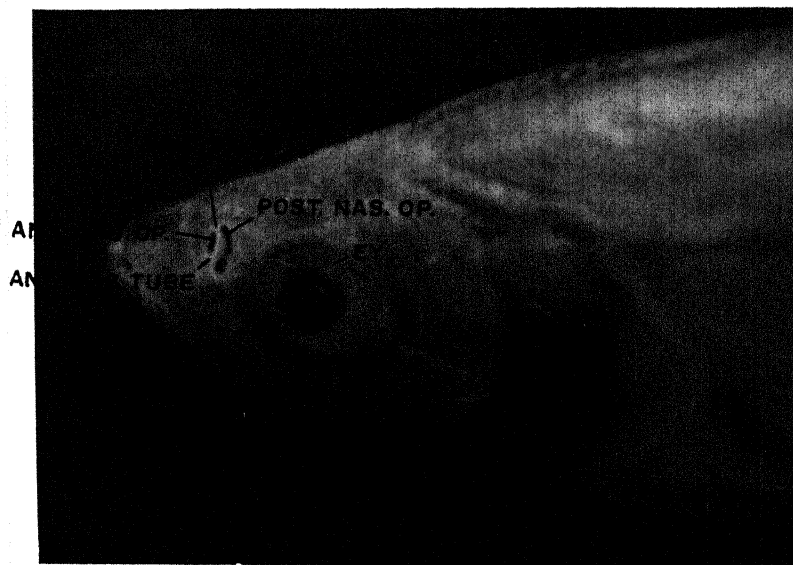


FIG. 72.

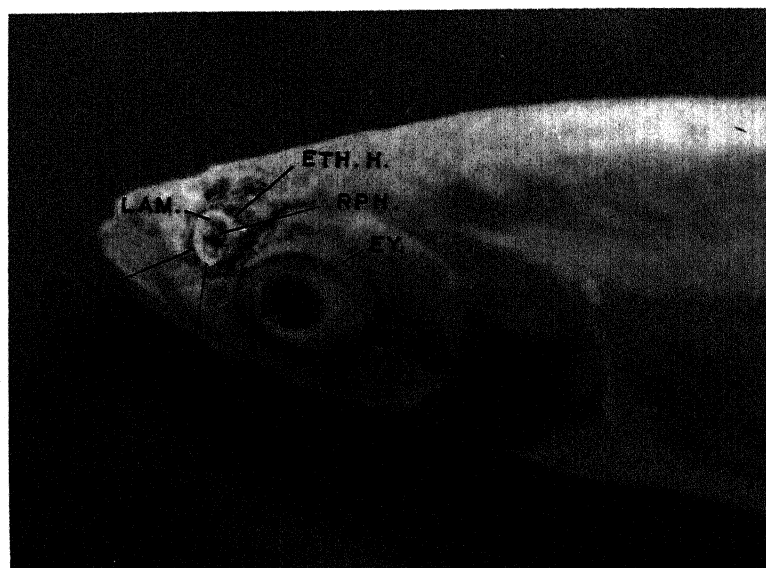


FIG. 73.

- Fig. 74A. Diagram of the lateral view of head of O. bacaila.
- Fig. 74B. Diagrammatic sketch of the olfactory chamber of O. bacaila to show anterior and posterior nasal openings with respect to eye.
- Fig. 74C. Diagrammatic sketch of the olfactory chamber of O. bacaila after removing the nasal flap with respect to eye.
- Fig. 74D. Diagrammatic sketch of the olfactory rosette of O. bacaila to show the arrangement of lamellae.
- Fig. 74E. A set of 1-16 lamellae from one half of the rosette of O. bacaila.

ANT.	- Anterior
ANT. NAS. OP.	- Anterior nasal opening
ANT. NAS. TUBE	- Anterior nasal tube
ETH. H.	- Ethmoidal half
EY.	- Eye
LAC. H.	- Lacrymal half
LAM.	- Lamellae
LAM. LESS AREA	- Lamellaeless area
NAS. FLAP	- Nasal flap
POST.	- Posterior
POST. NAS. OP.	- Posterior nasal opening
RPH.	- Raphe

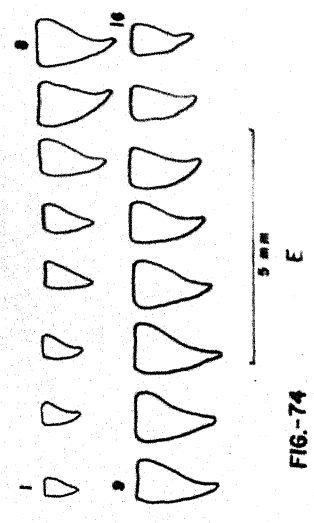
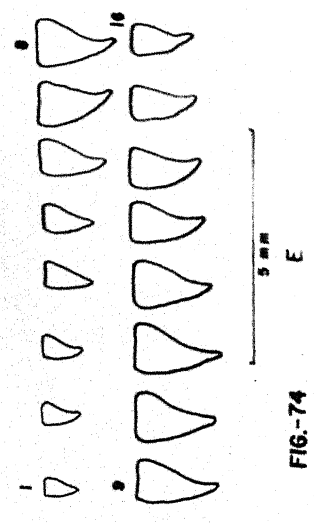
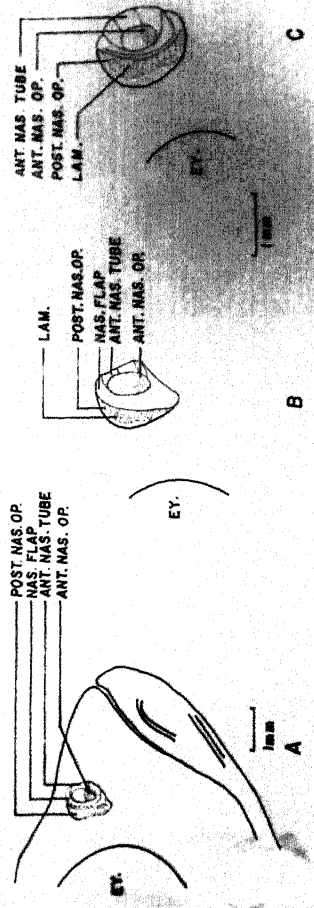


FIG. 74

Fig. 75. Diagrammatic sketch of the lateral view of skull of O. bacaila to show the bony elements, surrounding the olfactory chamber.

ART.	-	Articular
DEN.	-	Dentary
ENT.	-	Entopterygoid
ETH.	-	Ethmoid
FRON.	-	Frontal
LAC.	-	Lacrymal
LETH.	-	Lateral ethmoid
MAX.	-	Maxilla
MPT.	-	Metapterygoid
NAS.	-	Nasal
PAL.	-	Palatine
PAS.	-	Parasphenoid
PRE FRON.	-	Prefrontal
PRE MAX.	-	Premaxilla
Q.	-	Quadrate
ROST.	-	Rostral
SUP. ORB.	-	Supraorbital
2, 3, 4, 5,	-	Circumorbitals

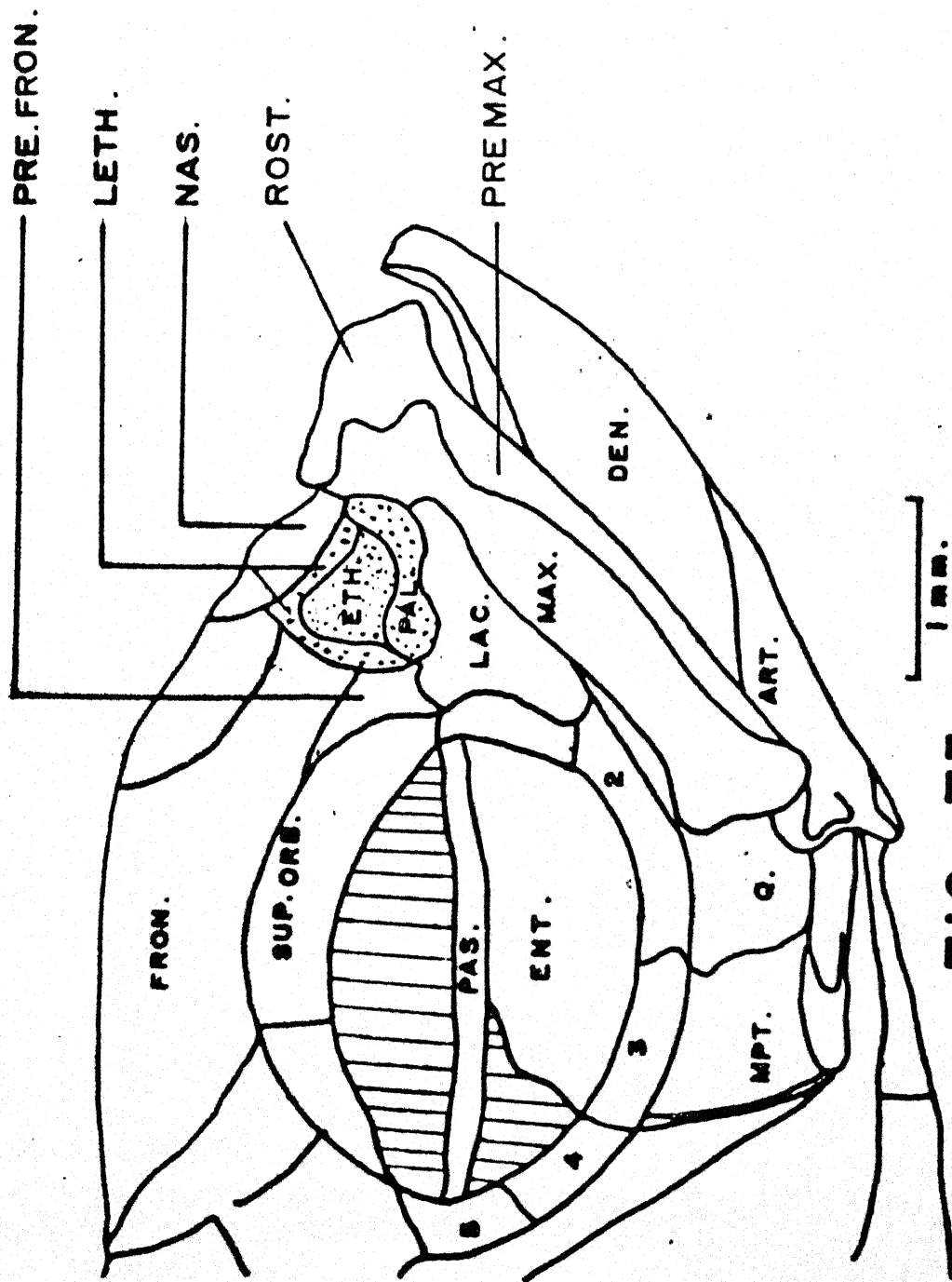
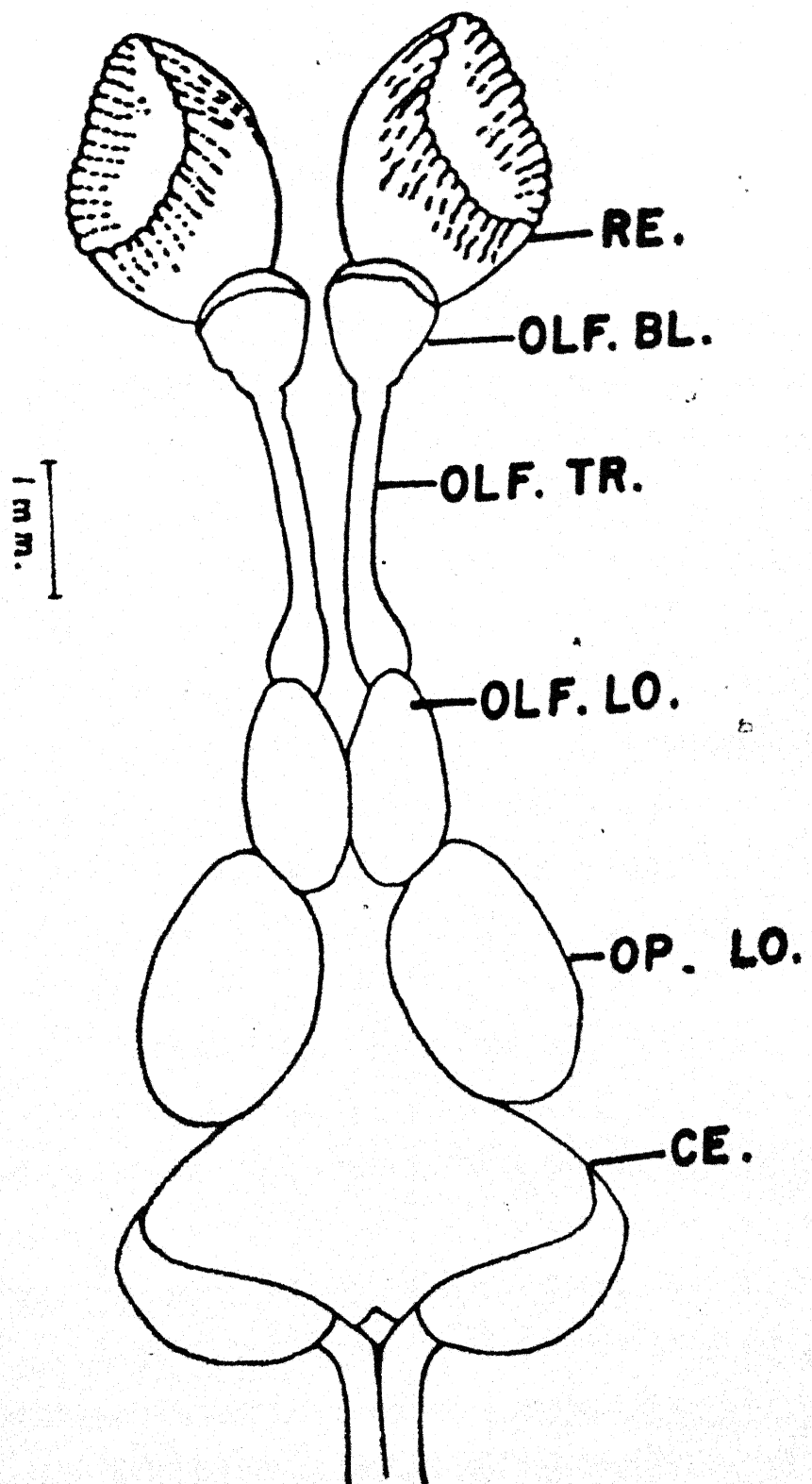


FIG.-75

Fig. 76. Diagrammatic sketch of the dissection of head of O. bacaila from dorsal side to show the relationship of brain with the rosette.

- |          |   |                 |
|----------|---|-----------------|
| CE.      | - | Cerebellum      |
| OLF. BL. | - | Olfactory bulb  |
| OLF. LO. | - | Olfactory lobe  |
| OLF. TR. | - | Olfactory tract |
| OP. LO.  | - | Optic lobe      |
| RE.      | - | Rosette         |



**FIG.-76**

MORPHOLOGICAL OBSERVATIONS OF OLFACTORY ORGAN OF  
OXYGASTER BACAILA (HAMILTON)

Oxygaster bacaila bears a pair of olfactory chambers (OLF. CHAM.) situated close to the eye orbits and away from the snout. The position of each chamber is anterolateral lying just against the anterior extremity of the eye orbit. The olfactory chamber is oval in shape and covered with integument which also contributes in the formation of a short tubular anterior (ANT. NAS. OP.) nasal openings. Each olfactory chamber is communicated outside by a pair of nasal openings which lie close to each other. The anterior nasal opening is placed on a short tube (ANT. NAS. TUBE) whose posterior margin is elevated which acts as a nasal flap (NAS. FLAP). It is upwardly and forwardly projected from the surface of the olfactory chamber and remains dipped in to the olfactory cavity by its ventral extension, dividing it transversely into anterior and posterior compartments. The posterior nasal opening lies on the surface of the head. The nasal flap stands as partition in between anterior and posterior nasal openings. The former is oval in shape and covers only a small portion of anterior most part of the olfactory chamber and leads into it in the form of a funnel. The latter is wide and semilunar, covering most of the posterior part of the olfactory chamber through which a major portion

of the rosette can be visualised under low magnification. The wide posterior nasal opening allows a constant touch of water with the olfactory lamellae (Figs. 72, 74A, 74B, 74C).

In a fish of 128 mm total length, the olfactory chamber is 1.462 mm in length and is placed at a distance of 2.351 mm from the snout and 0.936 mm from the anterior extremity of the eye orbit. The size of anterior nasal opening is 0.585 x 0.409 mm. The height of anterior nasal tube is 0.760 mm from the surface of the head. The posterior nasal opening is 0.292 mm wide having dorsoventral crescent of 1.345 mm.

The olfactory rosette (RE.) is rounded and completely lodged into the olfactory chamber, taking a shape of bowl. It possesses ventral convex and dorsal concave surfaces with large number of closely set lamellae (LAM., Figs. 73, 74D). A leaf shaped narrow raphe (RPH.) divides the olfactory rosette into ethmoidal and lacrymal halves. The raphe makes an angle of about  $35^{\circ}$  with respect to the body axis of the fish. A narrow lamellaeless area (LAM. LESS AREA) observed surrounding the lacrymal half of the rosette which becomes invisible in the ethmoidal half. This lamellaeless area can be understood as a rudimentary accessory nasal sac and may help in retaining the water during the course of its circulation through the olfactory

chamber. The chamber is not divided into central and peripheral channels due to the absence of linguiform processes in the lamellae (Fig. 74D).

The lamellae are arranged on either sides of the raphe which are closely packed with visible interlamellar spaces. They are curved structures and emerging out from the floor of the olfactory chamber, keeping their ventral surfaces attached with it. They are attached at right angle with the raphe in its anterior and middle region in a regular fashion on both the sides but in the posterior region they are attached obliquely, having their distal ends more elevated so as to come closer to the posterior nasal opening and avail the advantage of their constant exposure to the water. The smallest lamellae are observed in the anteriormost part of the rosette, indicating that their addition takes place at this end. The size of lamellae gradually increases towards the posterior (Figs. 73, 74D).

The floor of olfactory chamber is composed of palatoethmoidal complex. The palatine (PAL.) is a triangular bone constituting the anterior part of the olfactory chamber. Its anterior arm is attached with the maxilla (MAX.) and posterior two arms extend upto the middle of the chamber. The major part of the olfactory chamber is



scooped on the surface of the lateral ethmoid (LETH.). The chamber is partially guarded posterodorsally by frontal (FRON.), anterolaterally by the dorsal tip of the premaxilla (PREMAX.) and ventrally by lacrymal (LAC.). Anterodorsally the lateral wing of the ethmoid (ETH.) protects the olfactory chamber and forms internasal septum which along with its cartilage encircles the anterior nasal opening. A foramen for the passage of olfactory nerve is present at the union point of ethmoid and lateral ethmoid (Fig. 75).

The brain and its cranial connections are exposed after dissecting the fish from dorsal side and removing the frontal and parietals. The olfactory bulbs (OLF. BL.) are conspicuous and oval structures which receive nerves from the ventral convex surfaces of the rosettes. Each bulb posteriorly give rises olfactory tract (OLF. TR.) which terminates into the anterior part of telencephalon. The olfactory lobes (OLF. LO.) are considerably developed but are smaller than the optic lobes (OP. LO., Fig. 76).

#### Ecological coefficient:

The length of telencephalon, mesencephalon, area of two retinae and both the rosettes are taken into consideration for determining the ecological coefficient. Five fishes of different sizes ranging from 76 to 128 mm were

Table 4: Ecological coefficient of Oxygaster bacilla

Sl. No.	Total length (mm)	Number of lamellae Rosette		Total length of brain (mm)	Length of mesencephalon (mm)	Length of telencephalon (mm)	Ecological coefficient (Through lobes of brain) $\frac{\text{Length of telecephalon} \times 100}{\text{Length of mesencephalon}}$	Retinal area of both eyes (mm <sup>2</sup> )	Olfactory area of both rosette (mm <sup>2</sup> )	Ecological coefficient (Through ara) $\frac{\text{Olfactory area} \times 100}{\text{Retinal area}}$
		Right	Left							
1	76	22	23	6.727	2.340	1.638	70.000	18.075	70.219	388.486
2	81	24	24	6.903	2.340	1.755	75.000	19.354	80.778	417.371
3	117	29	29	8.365	2.632	1.755	66.679	34.408	135.936	395.070
4	120	30	30	8.365	2.653	1.773	66.830	34.408	150.724	438.049
5	128	32	32	8.541	2.691	1.872	69.565	38.836	198.237	510.446
Average				7.780	2.531	1.758	69.614	29.016	127.178	429.884

selected for calculating the above factor. It is found that the length of mesencephalon and telencephalon ranges from 2.340 to 2.691 mm and 1.638 to 1.872 mm respectively. The average ecological coefficient by brain lobe method stands 69.614 per cent, indicating amountable development of optic faculty (Table 4).

The ecological coefficient considering the area of both the retinae and that of two rosettes stands 429.884 per cent as an average. The area of two rosettes in all the five fishes ranges from 70.219 to 198.237 mm<sup>2</sup> and that of two retinae from 18.075 to 38.836 mm<sup>2</sup>. The above calculations revealed that O. bacaila is having considerable development of both the faculties putting it in a category of eye-nose fish, utilizing both the faculties efficiently in discharging the functions for locating the food, recognising the freight and courtship reactions etc. (Table 4).

The route of water circulation through the olfactory chamber of O. bacaila:

The posterior nasal opening is wide, covering most of the area of olfactory chamber and allowing the exposure of the posterior part of the olfactory rosette to the water. This provides a condition to the olfactory epithelium similar to those of gills which remain in a constant touch with water in all the conditions.



In addition to its rapid protrusion and retraction of jaws along with forward movement of fish permit the entry of water into the olfactory chamber through the anterior nasal opening. The water circulates in the olfactory chamber uniformly and lamellaeless area of lacrymal half of the rosette helps in retaining the water during this process (Figs. 74B, 74C, 74D). The fish in motionless condition enjoys constant contact of the olfactory lamellae with water (similar to gills) through the posterior nasal opening but during forward movement the water enters through the anterior nasal opening and expelled out from the posterior.

The route of transportation of water is shortest as compared to N. chitala, O. bimaculatus and N. nandus because most of olfactory chamber is exposed to water through the wide posterior nasal opening.

Fig. 77. Horizontal section of the rosette of O. bacaila showing the pattern of attachment of lamellae with raphe and their different shapes. Magnification X 100.

Fig. 78. Horizontal section of the rosette of O. bacaila passing through middle and hinder lamellae showing curving, knobbing, narrowing and pigmentation. Magnification X 150.

BM.	- Basement membrane
CON. TI.	- Connective tissue
CUR.	- Curving
HIN. LAM.	- Hinder lamellae
INI. LAM.	- Initial lamellae
INT. LAM. SP.	- Interlamellar space
KNO.	- Knobbing
MID. LAM.	- Middle lamellae
MSA.	- Mucosa
NAR.	- Narrowing
PIG.	- Pigment cell
RPH.	- Raphe
SMSA.	- Submucosa

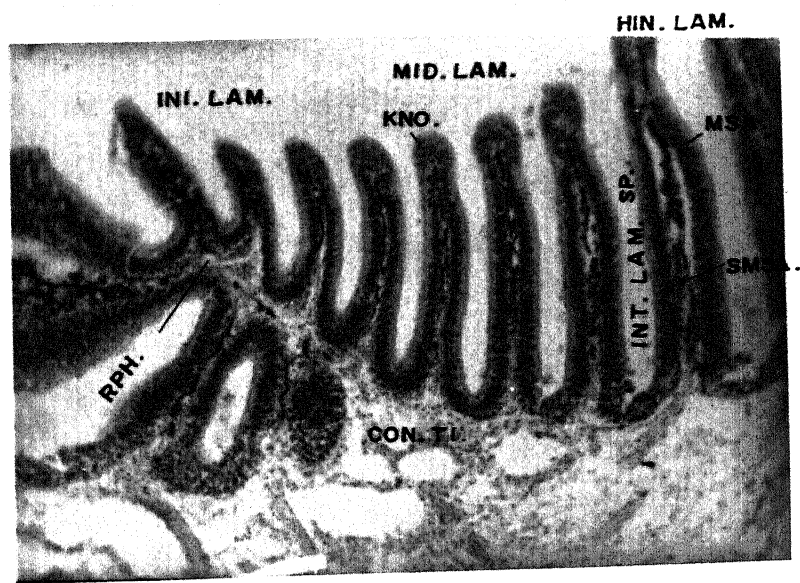


FIG. 77.

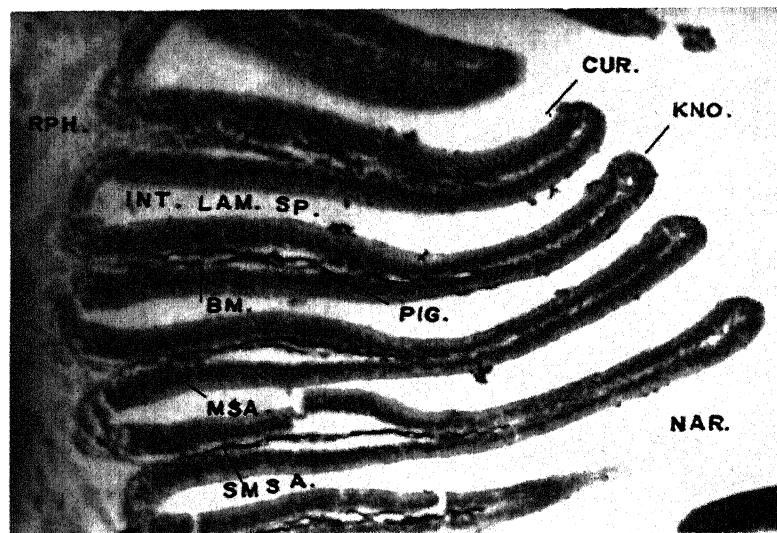


FIG. 78.

Fig. 79. Horizontal section of the rosette of O. bacaila passing through a set of middle lamellae showing trifurcation, clubbing and pigmentation. Magnification X 150.

Fig. 80. Horizontal section of the rosette of O. bacaila passing through distal region of the middle lamellae exhibiting cellular concentration in the knobs. Extrusion of cells, nonciliated supporting cells and pigmentation are of special reference. Magnification X 400.

BC.	- Basal cell
BCP.	- Blood capillary
BC. Z.	- Basal zone
BM.	- Basement membrane
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
CLUB.	- Clubbing
CON. TI.	- Connective tissue
EXT. C.	- Extrusion of cells
GC.	- Goblet cell
GR. BC.	- Grouping of basal cell
INT. LAM. SP.	- Interlamellar space
KNO.	- Knobbing
MSA.	- Mucosa
NCI. SC.	- Nonciliated supporting cell
PIG.	- Pigmentation
SC. Z.	- Supporting zone
SMSA.	- Submucosa
TRI.	- Trifurcation of lamella

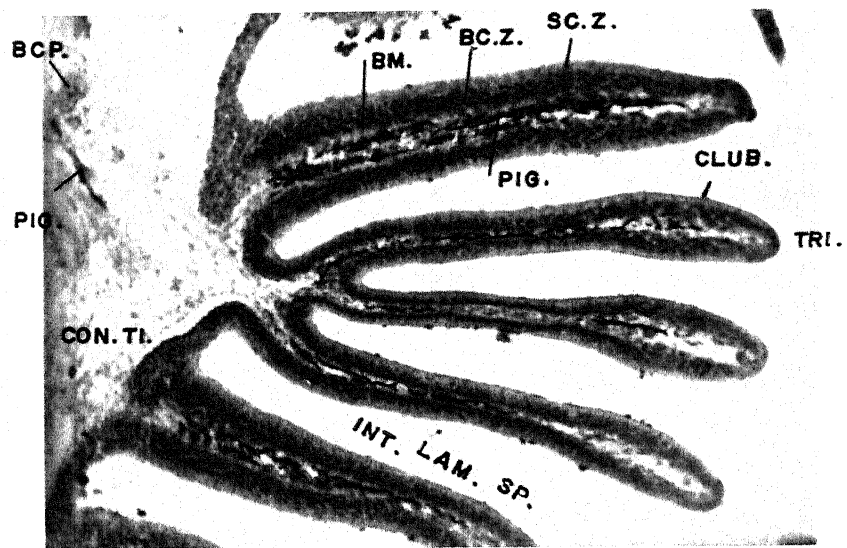


FIG. 79

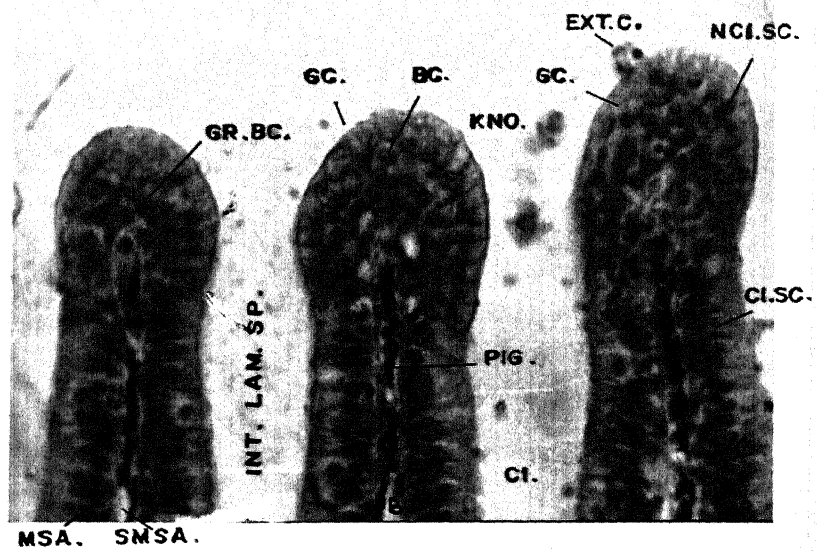


FIG. 80.

Fig. 81. Longitudinal section of distal end of the lamella of O. bacaila showing curving and extrusion of cells from the curve.  
Magnification X 400.

Fig. 82. Transverse section of the detached part of the lamella of O. bacaila which is pooled with all the cellular components, present in a full grown lamella with muciferous activity.  
Magnification X 400.

BCP.	- Blood capillary
CI.	- Cilia
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
CUR.	- Curving
EXT. C.	- Extrusion of cells
FI. OLF.	- Folium olfactorium
GR. BC.	- Grouping of basal cells
ME. GC.	- Megagoblet cell
MI. GC.	- Microgoblet cell
NCI. SC.	- Nonciliated supporting cell
OCI.	- Olfactory cilia
SMSA.	- Submucosa
SR.	- Spindle shaped receptor cell

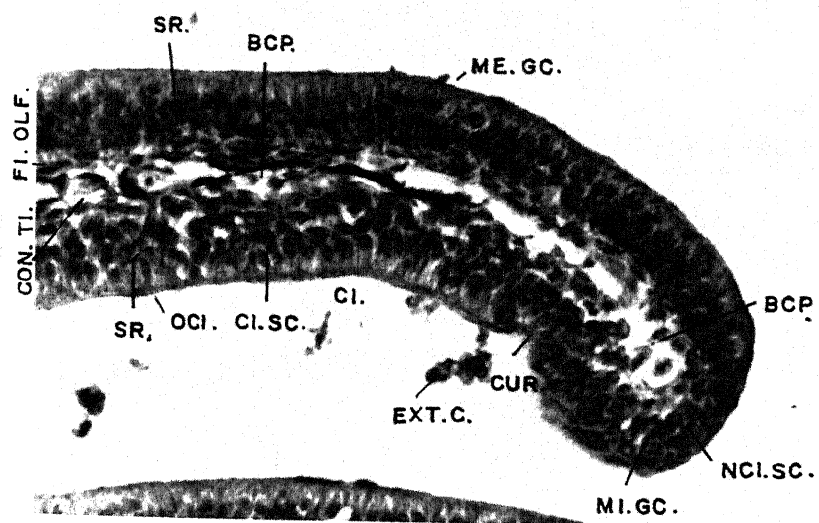


FIG. 81.

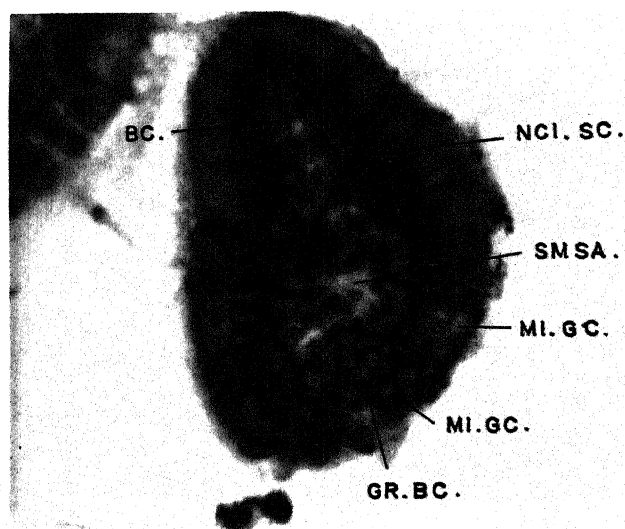
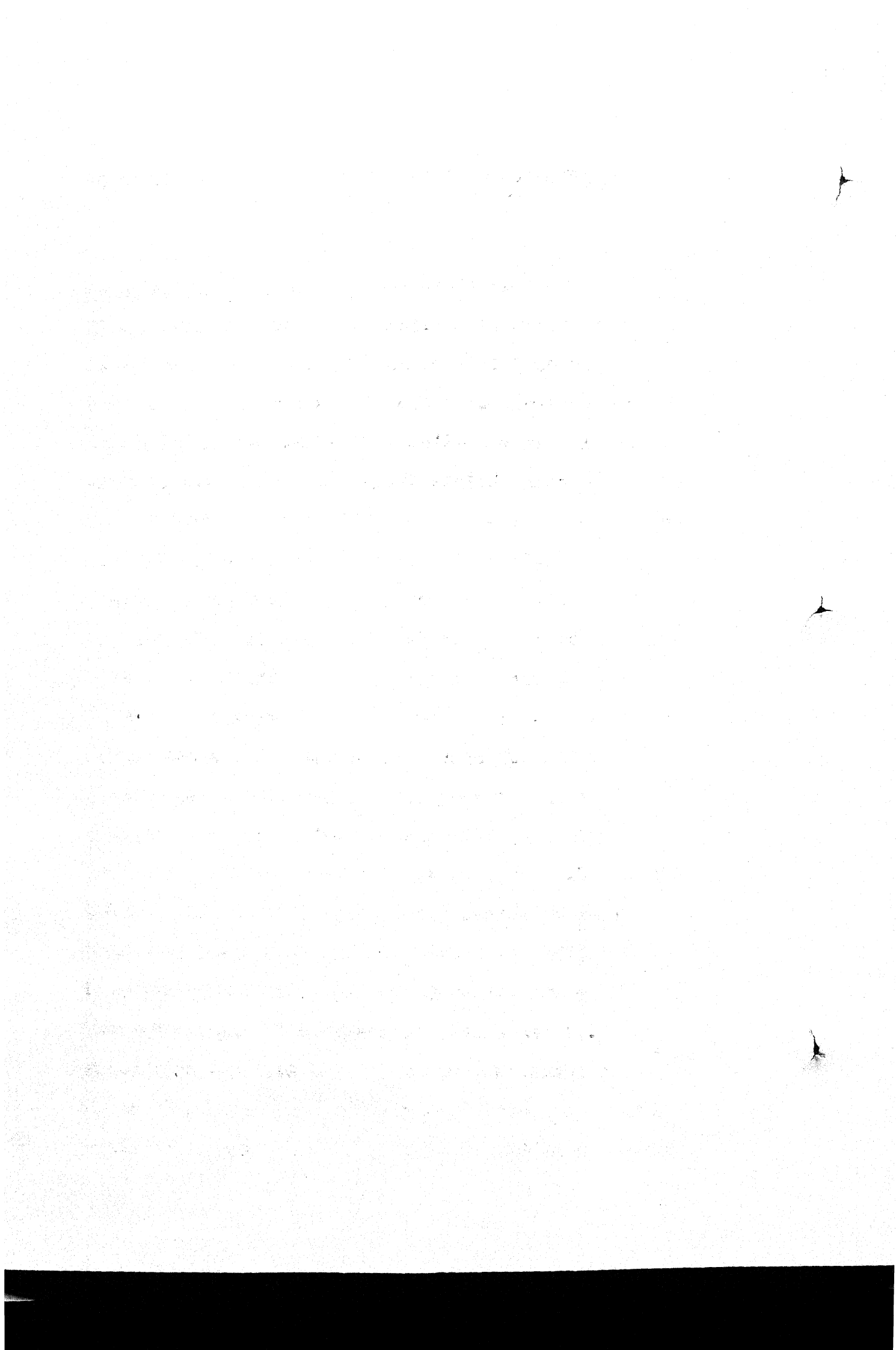
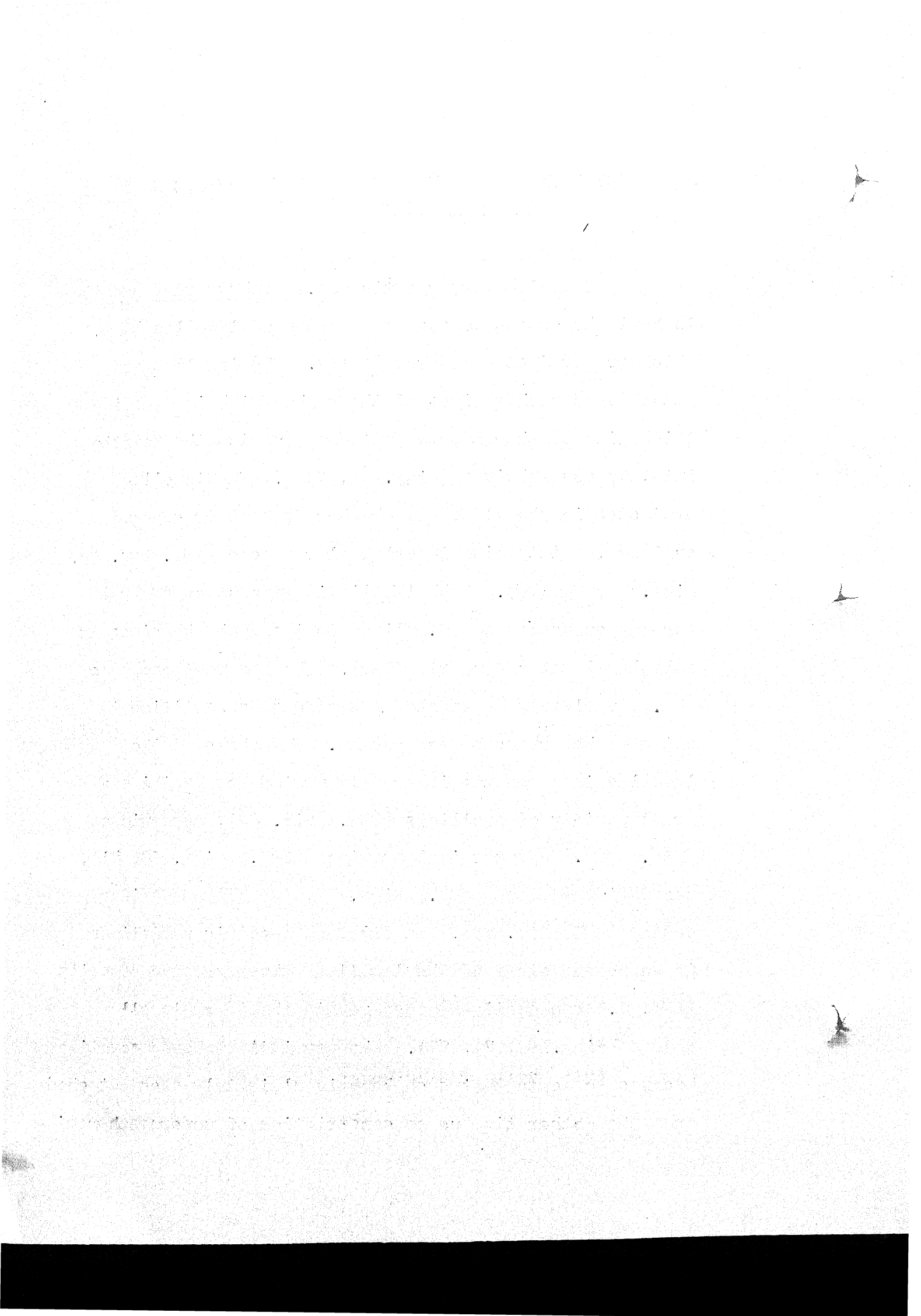


FIG. 82.



HISTOLOGICAL OBSERVATIONS OF OLFACTORY ORGAN OF  
OXYGASTER BACAILA (HAMILTON)

The olfactory rosette (RE.) of Oxygaster bacaila is bowl shaped and possesses a number of lamellae (LAM.) which are projected ventrodorsally. The lamellae are attached on either sides of the raphe which is a median thickening of the olfactory floor, dividing the rosette into two equal halves (Figs. 73, 74D). The lamellae are projected in the olfactory chamber from their concave surfaces, maintaining interlamellar spaces (INT. LAM. SP., Figs. 77, 78, 79). Each lamella is made up of central core or submucosa (SMSA.) lined on its both the sides by cellular layer of mucosa (MSA.). The basement membrane (BM.) is clearly demarcated and stands as partition in between the submucosa and mucosa. The shape of the lamellae in a rosette is greatly varied and exhibits a great variety of swellings (SWE., Fig. 83), narrowings (NAR., Fig. 78), terminal curvings (CUR., Figs. 78, 81), terminal knobblings (KNO., Figs. 77, 78, 80) and trifurcation (TRI, Fig. 79). In all such specific variations in shape and sizes of the lamellae, the extrusion of cells (EXT. C.) can easily be observed in the inter-lamellar spaces (Figs. 80, 81, 82). The terminal knobbing sometime becomes so acute that such knob is ultimately seen detached from the mother tip due to constriction of underneath region



(Figs. 78, 82). Such detachments are pooled with all the cellular components present in a lamella. The muciferous activity is greatly observed in the floor of olfactory chamber (Figs. 84, 85) and in the posterior lamellae of the rosette (Figs. 86, 87, 89). The initial lamellae show no muciferous activity (Figs. 81, 83, 88, 91). As the lamellae enlarge in size, the turgor (TUR.) formation becomes more prominent which may be due to the accumulation of the bundles of connective tissue fibres intermingled with branched fibroblasts and other cells (Figs. 92). From the histological point of view, the lamellae can be divided into three categories: the initial, middle and hinder lamellae.

The initial lamellae possess well composed structure with normal submucosa (SMSA.) and mucosal (MSA.) zone. Terminal knobbing is not very prominent although their initiation can be observed in these lamellae. These lamellae exhibit no muciferous activity and are provided with stratified columnar epithelium. Pigmentation (PIG.) is observed in the submucosa of these lamellae (Figs. 81, 91).

The middle lamellae have their proximal structure broad which extends terminally in a trend of narrowing and curving (Fig. 78). These lamellae exhibit a feature of trifurcation. The trifid lamellae are observed with narrow



proximal and club shaped terminal ends. The submucosa of this trifurcation remains united and gives an impression that all these three sublamellae are coming out from one root (Fig. 79).

The hinder lamellae show tremendous muciferous activity and are provided with enlarged submucosa along with well composed mucosal zone (Figs. 92, 93). The ciliation is visible. The muciferous activity, in the terminal and middle zone of these lamellae as well as the floor of olfactory epithelium, can be successfully demonstrated in the present study of O. bacaila (Figs. 86, 89, 90, 92).

The olfactory epithelium of O. bacaila comprises of supporting cells, receptor cells, goblet cells and basal cells.

#### The supporting cells:

The supporting cells (SC.) are richly distributed and provided with prominent nuclei which bear chromatin material and nucleoli. They are of two types: the ciliated and nonciliated supporting cells. The ciliated supporting cell possesses broad and columnar distal limb (DE. CI. SC.), extending up to the free or peripheral surface where it ends by well demarcated tip. The cilia are planted on the



basal granules present on the terminal tips of ciliated supporting cells and projected into the interlamellar spaces. The nucleus (NU. CI. SC.) of ciliated supporting cell has clear outline and takes dark stain of haematoxylin. The proximal limb of this type of supporting cell is not clearly traceable because of the presence of thick layer of basal cells beneath it (Figs. 81, 83, 87, 89, 90, 91). These supporting cells are densely distributed in the proximal and middle region of initial and middle lamellae but rarely observed in hinder ones, floor of olfactory chamber and lamellaeless zone.

The nonciliated supporting cells (NCI. SC.) are observed in the hinder lamellae, floor of olfactory epithelium, knobs and curvings (Figs. 80, 81, 84, 85). These cells are also observed intermingled among the ciliated supporting cells. The nonciliated supporting cell is provided with a short body and almost spherical nucleus (NU. NCI. SC.). The nucleolus and chromatin material are not properly visible. The muciferous activity in non-ciliated supporting cells is very prevalent and clearly observed in the middle and hinder lamellae as well as in the floor of olfactory chamber (Figs. 84, 85). Due to muciferous activity in nonciliated supporting cells, some zones of middle and hinder lamellae and floor of olfactory chamber are commonly supplied with mucous secretory goblet

Fig. 83. Longitudinal section of the lamella of O. bacaila showing swelling in the middle region with pigmentation in submucosa. Magnification X 400.

Fig. 84. Transverse section of the rosette of O. bacaila passing through the floor of olfactory chamber showing micro and megagoblet cells. Magnification X 1000.

BC.	- Basal cell
BCP.	- Blood capillary
BC. Z.	- Basal zone
BM.	- Basement membrane
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
CON. TI. FIB.	- Connective tissue fibre
DE. NCI. SC.	- Distal end of nonciliated supporting cell
FBC.	- Fibroblast cell
FI. OLF.	- Folium olfactorium
HIS.	- Histiocyte
INT. LAM. SP.	- Interlamellar space
MI. GC.	- Microgoblet cell
MU.	- Mucous
NCI. SC.	- Non-ciliated supporting cell
NU. GC.	- Nucleus of goblet cell
NU. NCI. SC.	- Nucleus of nonciliated supporting cell
FIG.	- Pigmentation
SR.	- Spindle shaped receptor cell
SWE.	- Swelling
TH. ME. GC.	- Theca of megagoblet cell

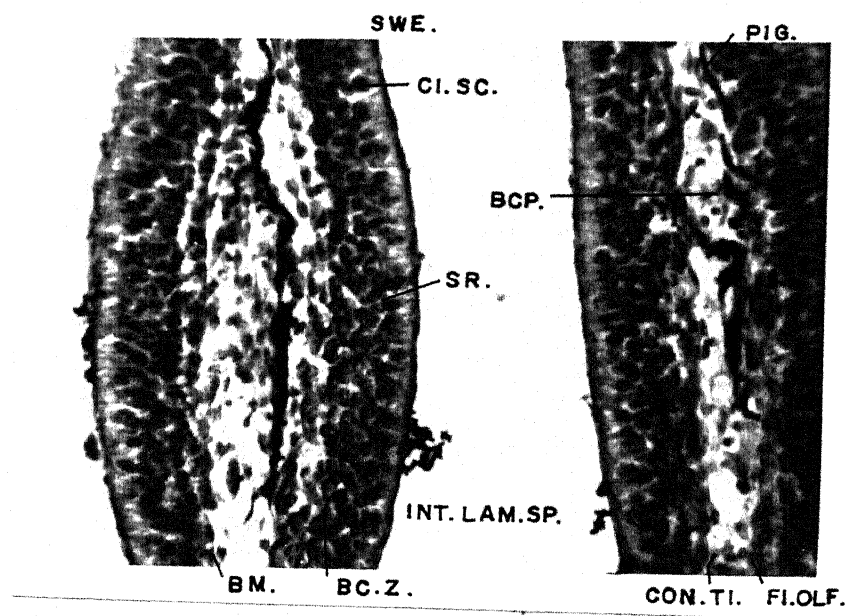


FIG. 83.

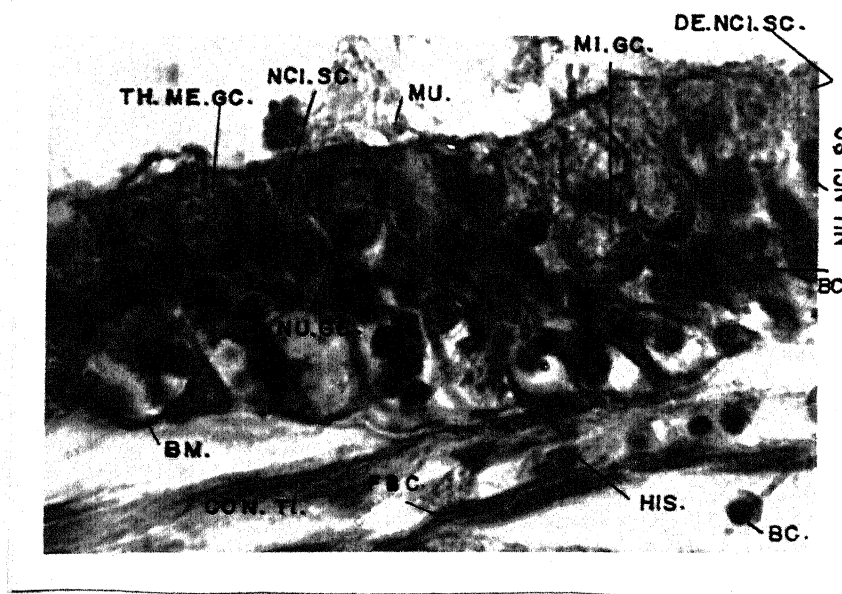


FIG. 84.

Fig. 87. Transverse section of the middle lamella of O. bacaila showing primary neurones, ciliated supporting cells, spindle shaped receptor cells and the elements of submucosa. Magnification X 1000.

Fig. 88. Transverse section of the initial lamella of O. bacaila showing ciliation and receptor cells. Magnification X 600.

BC.	- Basal cell
BM.	- Basement membrane
CI.	- Cilia
CON. TI.	- Connective tissue
DE. CI. SC.	- Distal end of ciliated supporting cell
DN. PN.	- Dendrite of primary neurone
DN. SR.	- Dendrite of spindle shaped receptor cell
FBC.	- Fibroblast cell
FGN. MU.	- Foreign material entangled in mucous
GC.	- Goblet cell
HIS.	- Histiocyte
NU. CI. SC.	- Nucleus of ciliated supporting cell
NU. GC.	- Nucleus of goblet cell
NU. SR.	- Nucleus of spindle shaped receptor cell
OCI.	- Olfactory cilia
FIG.	- Pigmentation
PN.	- Primary neurone
SR.	- Spindle shaped receptor cell
TH. GC.	- Theca of goblet cell

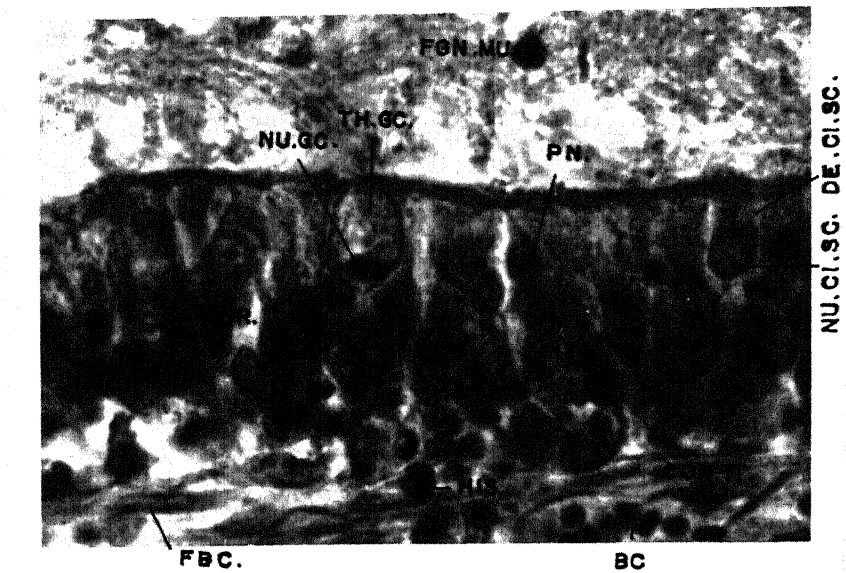


FIG. 87.

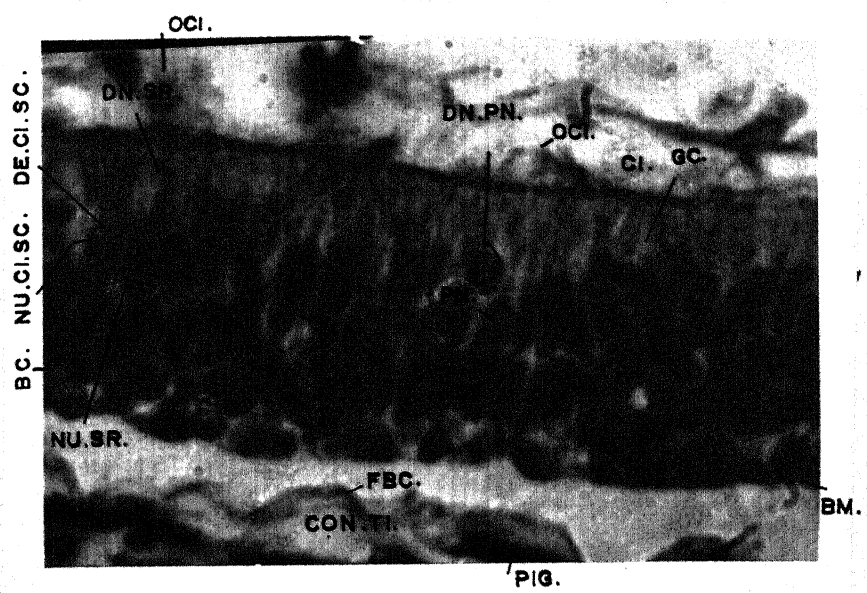


FIG. 88.

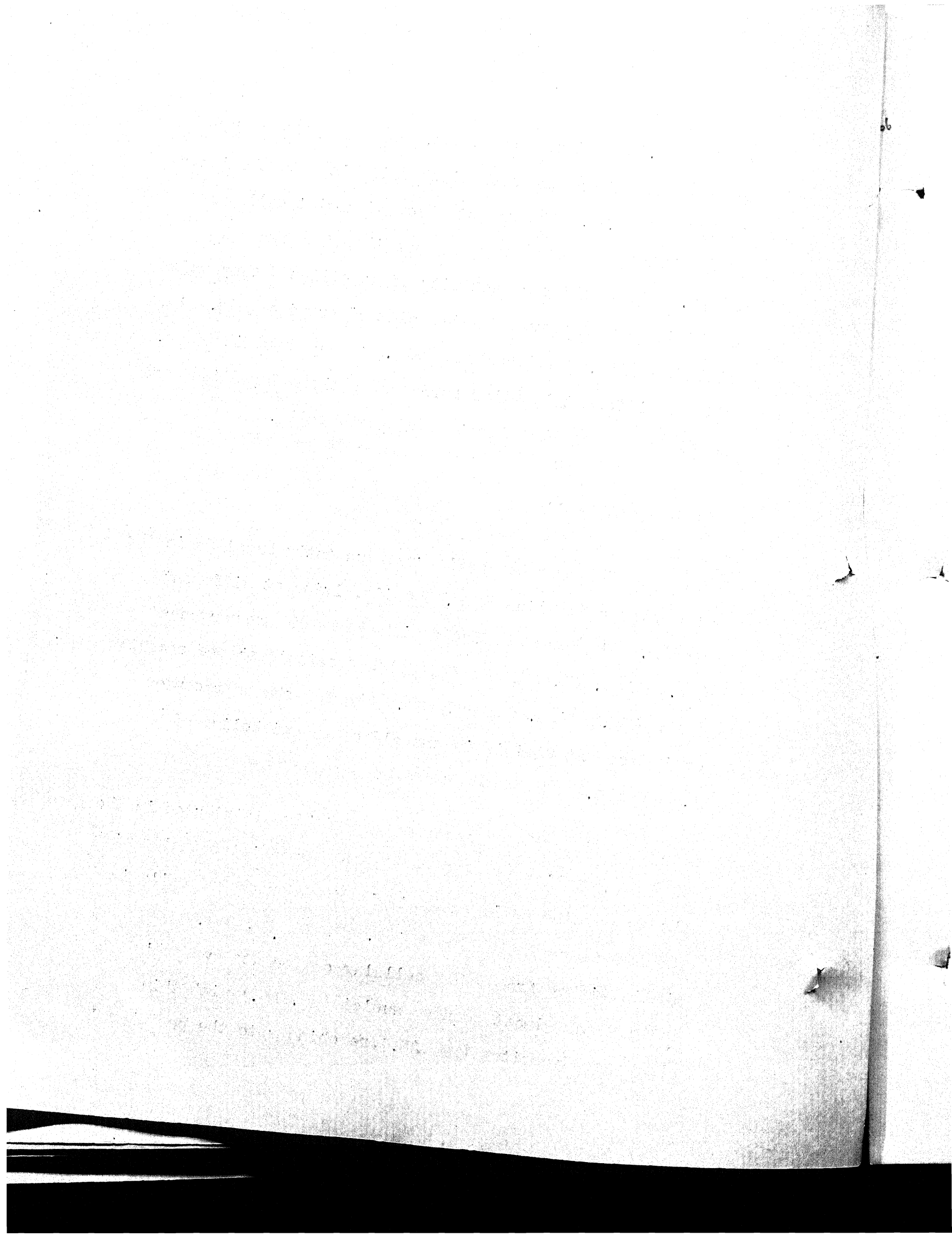


cells (GC.) of different stages, some are filled with mucous and others are seen discharging it into the inter-lamellar spaces. The vacant theca of goblet cells are also visible, permitting a way for the migration of basal cells. The muciferous activity of nonciliated supporting cells is also observed at the point of curving (Fig. 81), clubbing (Fig. 79), knobbing (Fig. 80) and swelling (Fig. 83) in different lamellar surfaces as these formations are possible due to the migration of basal cells.

#### The receptor cells:

The receptor cells are abundantly supplied in the olfactory epithelium of O. bacaila, lying at different depths. They can be distinguished as primary neurones (PN., Figs. 86, 87, 88, 89, 90) and spindle shaped receptor cells (SR., Figs. 86, 89, 90). The rod shaped receptor cells are not visible in the olfactory epithelium of O. bacaila.

The primary neurones are richly distributed in the tips of lamellae as well as also observed intermingled with the supporting cells and spindle shaped receptor cells in the olfactory epithelium (Figs. 87, 88, 89, 90). They are distinguished from other cellular components by darkly stained and almost rounded nuclei (NU. PN.) with thin elongated dendrites (DN. PN.), reaching upto the peripheral



surface of the lamellae. Their existence is also noticed in the posterior lamellae where supporting cells are seen transforming into goblet cells by their muciferous activity (Figs. 89, 90). The primary neurones extend towards the central core or submucosa by their axons to join folium olfactorium (FI. OLF.). The primary neurones exist independently and no synapse formation is observed with any other receptor in the olfactory epithelium of O. bacaila.

The spindle shaped receptor cells (SR.) are uniformly and commonly observed in all the regions of olfactory epithelium and found distributed among the supporting cells. They are situated deep in the mucosa below the supporting zone, intermingled with basal cells. The spindle shaped receptor cell is having elongated body with oval nucleus (NU. SR.). The nucleus contains visible chromatin material and one or two nucleolus. This kind of receptor cell extends to the peripheral surface by a thick and well demarcated dendrite which is having expanded tip. The ciliary projection from the expanded tip of the dendrite represents the formation of olfactory vesicle which may bear one or more cilia (OCI.) or some microvilli projecting in the interlamellar spaces (Figs. 82, 86, 88).

#### The goblet cells:

The goblet cells (GC) are richly distributed in

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the olfactory mucosa of middle and hinder lamellae of O. bacaila but in the initial ones they are absent. The goblet cells are produced by the muciferous activity of basal and supporting cells. From their origin point of view, a distinction can be made into micro (MI. GC.) and megagoblet (ME. GC.) cells. The former are produced with the result of muciferous activity of basal cells whereas the latter from the supporting cells. The mucous discharge, in the interlamellar spaces, is quite prevalent and foreign material (FGN. MU.) is seen entangled within it (Figs. 87,90).

The megagoblet cells (ME. GC.) are very common in occurrence in the supporting zone (SC. Z.) and formed with the result of muciferous activity of supporting cells. The megagoblet cell is made up of elongated cup like theca (TH. ME. GC.) which some times possesses a beak (BK.) like projection in the interlamellar spaces (Figs. 86, 89, 92). This may be a device for the easy discharge of mucous in the interlamellar spaces. The nucleus (NU. ME. GC.) is prominent, takes a dark stain and lies at the bottom of theca where chromatin material is visible. The megagoblet cells can be seen in different stages from formative stage to empty theca after the discharge of mucous (Figs. 84, 85, 86, 88, 89, 90).

The microgoblet cells (MI. GC.) are rare in occurrence but visible in the basal zone (BC. Z.) of the

Fig. 89. Transverse section passing through middle region of hinder lamella of O. bacaila showing the presence of primary neurone, spindle shaped receptor cell and detailed cellular components of submucosa. Magnification X 1000.

Fig. 90. Transverse section of the hinder lamella of O. bacaila passing through its distal region showing the details of primary neurone, spindle shaped receptor cell, ciliated supporting cells with special reference to dendrites of receptor cells terminating in the expanded tips bearing microvilli. Mucous entangling foreign material is also visible. Magnification X 1000.

BK.	- Beak
CON. TI.	- Connective tissue
DE. CI. SC.	- Distal end of ciliated supporting cell
DN. PN.	- Dendrite of primary neurone
DN. SR.	- Dendrite of spindle shaped receptor cell
FBC.	- Fibroblast cell
FGN. MU.	- Foreign material entangled in mucous
FI. OLF.	- Folium olfactorium
HIS.	- Histocyte
INT. LAM. SP.	- Interlamellar space
ME. GC.	- Megagoblet cell
NU. CI. SC.	- Nucleus of ciliated supporting cell
NU. GC.	- Nucleus of goblet cell
NU. PN.	- Nucleus of primary neurone
NU. SR.	- Nucleus of spindle shaped receptor cell
PN.	- Primary neurone
SR.	- Spindle shaped receptor cell

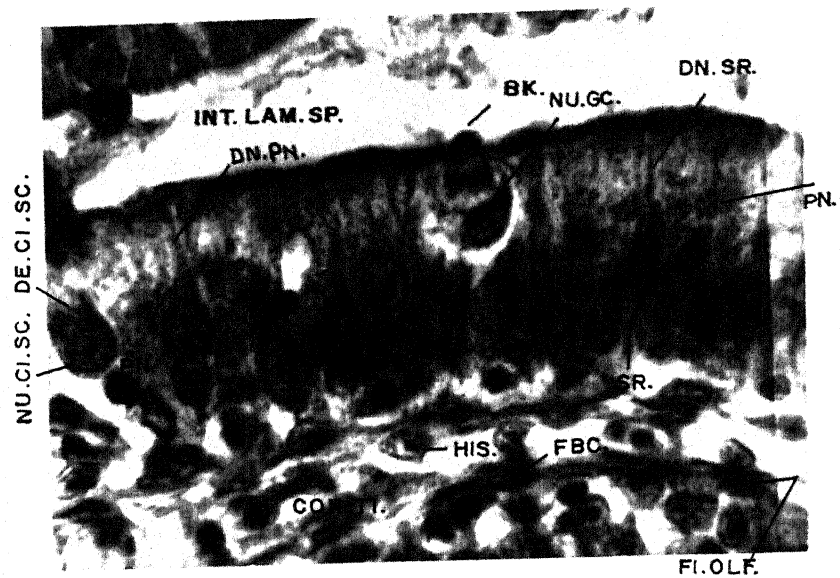


FIG. 89.

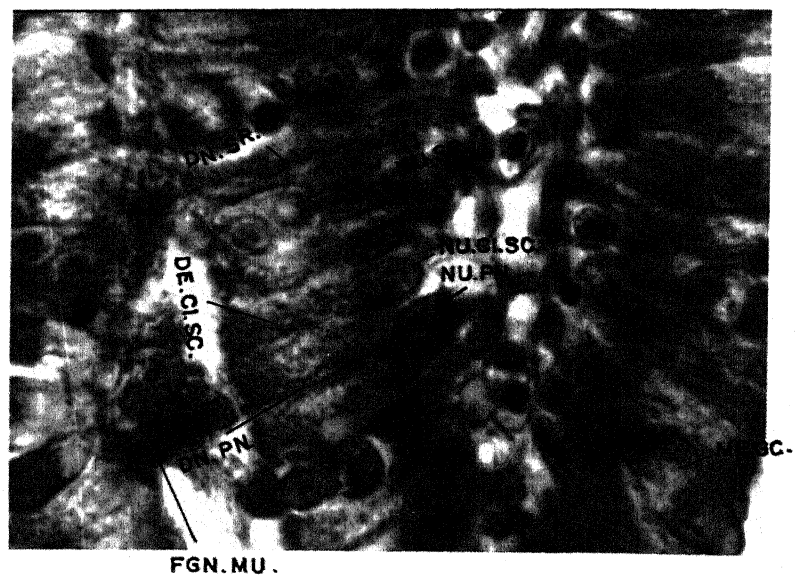


FIG. 90.

91. Horizontal section of the rosette of O. bacaila passing through initial lamellae showing their attachment with raphe and maintenance of interlamellar spaces. Magnification X 400.
92. Longitudinal section of hinder lamella of O. bacaila showing turger for strengthening the lamella. Magnification X 400.

BC.	- Basal cell
BCP.	- Blood capillary
BL. SI.	- Blood sinus
BM.	- Basement membrane
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
CON. TI. FIB.	- Connective tissue fibre
FBC.	- Fibroblast cell
FI. OLF.	- Folium olfactorium
HIS.	- Histiocyte
INT. LAM. SP.	- Interlamellar space
ME. GC.	- Megagoblet cell
MI. GC.	- Microgoblet cell
MSA.	- Mucosa
OCI.	- Olfactory cilia
PIG.	- Pigmentation
RPH.	- Raphe
SC.	- Supporting cell
SMSA.	- Submucosa
SR.	- Spindle shaped receptor cell
TUR.	- Turger

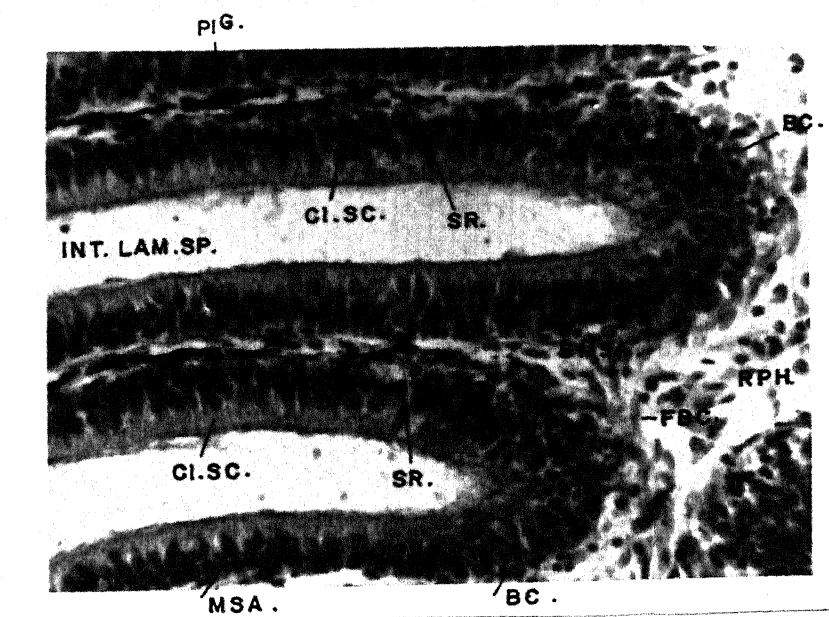


FIG. 91.

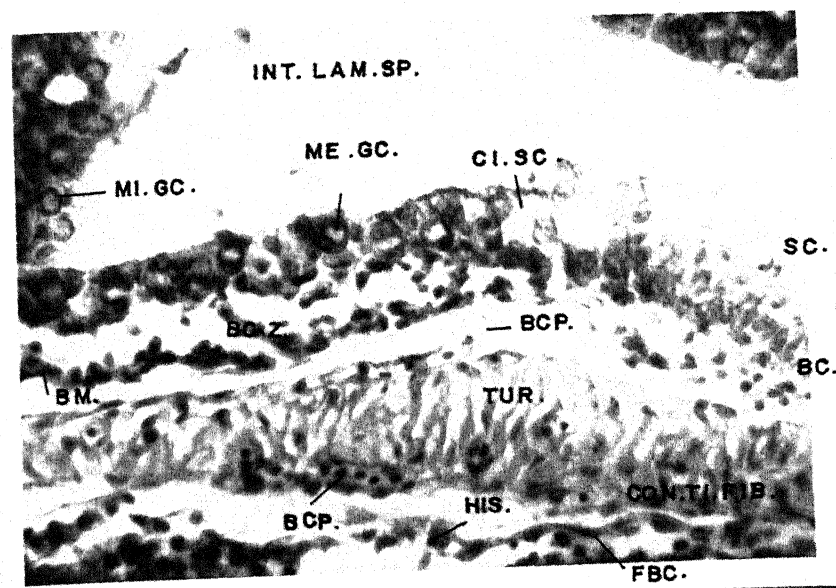


FIG. 92.

Fig. 93. Horizontal section of the rosette of O. bacaila passing through raphe showing its cellular details. Magnification X 400.

Fig. 94. Magnified photograph of the intact olfactory rosette of N. chitala

ADNAS. H.	- Adnasal half
ANT.	- Anterior
BL. SI.	- Blood sinus
CI. SC.	- Ciliated supporting cell
CON. TI.	- Connective tissue
FBC.	- Fibroblast cell
FI. OLF.	- Folium olfactorium
INT. LAM. SP.	- Interlamellar space
LAM.	- Lamella
LAM. LESS AREA	- Lamellaeless area
LING.	- Linguiform process
NAS. H.	- Nasal half
OCI.	- Olfactory cilia
PIG.	- Pigmentation
POST.	- Posterior
RPH.	- Raphe
SR.	- Spindle shaped receptor cell

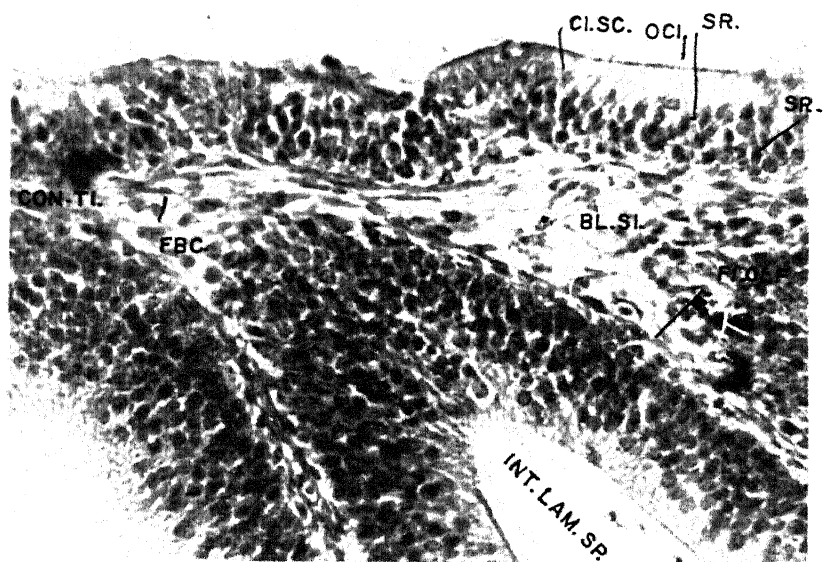


FIG. 93.

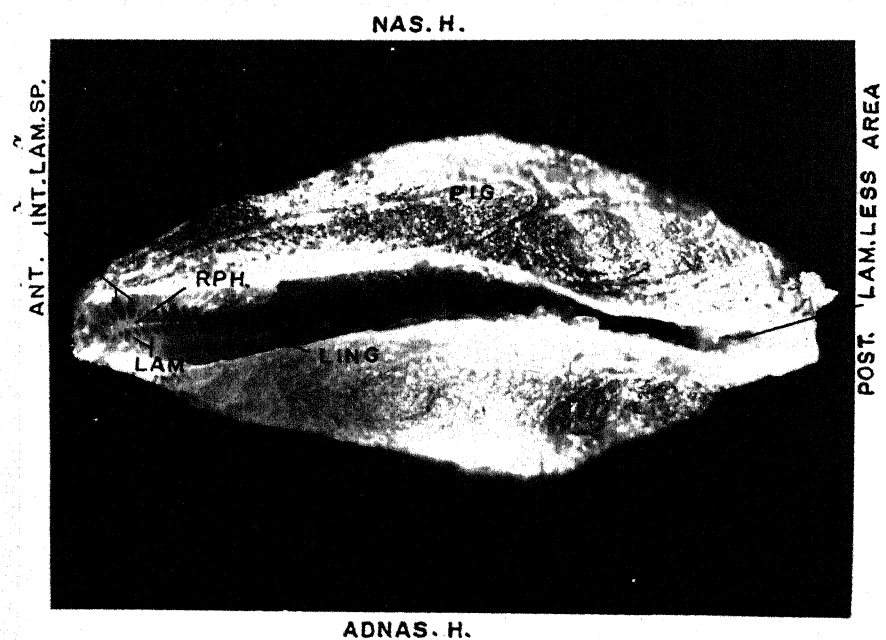


FIG. 94.

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olfactory mucosa of hinder lamellae and in the floor of olfactory chamber. They are having rounded body with compressed nucleus where chromatin material is invisible. These goblet cells are produced in the basal zone and ascend towards the periphery of mucosa for the discharge of their mucous. The theca is short, somewhat spherical and can be clearly distinguished from megagoblet cells (Figs. 81, 82, 84, 92).

The basal cells:

The basal cells (BC.) form three or four layers of basal zone (BC. Z.) just above the basement membrane (BM.). They are accumulated in the zones of curving, knobbing, swelling, clubbing and in the hinder lamellae. The basal cell is rounded or oval in shape with darkly stained nucleus (NU. BC.) and clearly visible cytoplasm. The basal cells exhibit a tendency of migration which leads to take the shapes of specific formations. The knobs are seen pooled with basal cells which in later stages cause the elongation of lamellae (Figs. 80, 81, 82, 83). In well composed lamellae they are present in regular layers, demarcated as basal zone (Figs. 79, 91, 93) but in other zones of mucosa these cells exhibit some formative activity (Figs. 81, 83, 86, 89, 90, 92). The basal cells also reveal positive muciferous activity in the terminal tips and other parts of the floor of olfactory chamber (Figs. 82, 84, 92).

### The central core or submucosa:

The submucosa (SMSA.) exhibits great variation in its development, ranging from narrow and well composed central core of initial lamellae to enormously broad and scattered in hinder ones. It is filled with dense connective tissue fibres (CON. TI. FIB.). The connective tissue of central core of lamella is in continuation with the central core of raphe (Figs. 77, 78, 79, 91, 93) through which nutritional, nervous and supporting supply is attributed to the distal region of the lamellae. In the hinder and in some middle lamellae, the connective tissue fibres are intermingled with other contents of matrix, taking the shape of turgor (TUR., Fig. 92) which provides support to enormously developed hinder lamellae and keep them straightly projected through posterior nasal opening for constant exposure to water. In the condition of trifurcation, the central core is completely trifid from the base of the mother lamella and ultimately remains communicated with the central core of raphe (Fig. 79). The submucosa of O. bacaila is supplied with basal cells (BC.), fibroblasts (FBC.), histiocytes (HIS.), pigment cells (FIG.), blood capillaries (BCP.) and different types of connective tissue fibres (Figs. 81, 83, 86, 87, 88, 89, 92).

The raphe:

Unlike O. bimaculatus and N. chitala, the raphe of O. bacaila is made up of nonciliated and ciliated epithelium which is supplied with spindle shaped receptor cells, bearing olfactory cilia. The leaf shaped narrow raphe bears closely packed lamellae on its either sides. The submucosa is broad and lined on both the sides by a well demarcated basement membrane which is in continuation with the lamellar outgrowths. This gives a wavy appearance to the submucosa, basement membrane and the cellular epithelial lining of the raphe. The submucosa of raphe is filled with connective tissue which is supplied with fibroblasts, blood capillaries, pigment and basal cells. The nerve fibres can also be seen in the submucosa of raphe. The mucosa is lined by ciliated supporting cells which are rarely alternated by receptor cells. Due to the supporting and sensory nature of raphe, it may probably be assumed as a central lamella, giving rise to number of lamellae in O. bacaila (Figs. 77, 79, 91, 93).

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# DISCUSSION OF MORPHOLOGY

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The nasal openings:

Each olfactory chamber characteristically bears two nasal openings, anterior inlet and posterior outlet which are separated by nasal flap or bridge. In fishes sense of realisation of odorants and other chemical substances is through the water current, passing regularly in the olfactory chamber. This sense of realisation is quite different from the higher vertebrates where sense of olfaction is realised through the breathing air. Dipnoans, Holocephalids and Elasmobranchs have external nostrils which lead to the buccal cavity either in the form of short canal or deep naso-oral groove. In Petromyzon, the naso-oral groove is blind but in Hag fishes it opens into the buccal cavity (Norman, 1963).

Elasmobranchs have a pair of slit like nasal openings on the ventrolateral side of the snout. The flap of skin extending across the middle of each nostril more or less completely divides it into two parts. The two nostrils are so adjusted so that one serves to intake the water and other for exit (Allison, 1953; Lagler et al., 1962; Malyukina et al., 1969; Hara, 1975). In bony fishes the nostrils are usually situated on the dorsal side of the head. Each is divided into incurrent and excurrent passages. A direct connection between the nasal sac and the mouth cavity

by means of nasal passage, is reported for the first time in Dipnoans (Bertmar, 1965). In all the teleosts including eels, family Echelidae and opichthidae (Atz, 1952). The internal and external nostrils lie at the opposite ends of the nasal passages and having no connection with the buccal cavity.

According to Bateson (1889), Burne (1909), Teichmann (1954), Kleerekoper (1969), Norman (1963), Lagler (1963), Hara (1975), the olfactory chamber of most of the bony fishes bears two nasal openings which show considerable variation in their shape, size and location. In some fishes anterior nasal opening is widely separated from the posterior while in others they lie very close to each other. Cichlids (Cichlidae) and certain Wrasses (Labridae) have single nasal opening in their olfactory chamber (Norman, 1963).

Among recent fishes, only Scalpins, Cottus (Lagler et al., 1962), Gasterosteus (Pipping, 1926; Lagler et al., 1962); Quab (Pipping, 1926; Liermann, 1933); Xenentodon (Gupta and Srivastava, 1973; Singh, 1972) possess single nasal opening in their olfactory chamber. According to Burne (1909) the presence of single nasal opening may be the condition created by the elevation of the floor and subsequent rupture of the bridge between the nostrils.

In the present study of Nandus nandus, Ompok bimaculatus, Notopterus chitala and Oxygaster bacaila, the

olfactory chambers of all these four fishes bear incurrent anterior and excurrent posterior nasal openings. The anterior nasal openings in O. bacaila and O. bimaculatus bear tube. Burne (1909) reported that the anterior tubular opening is the characteristic of the flat fishes, eels, siluroids and Ophiocephalids. The presence of anterior tubular nasal opening in Siluroid, O. bimaculatus support the Burne's (1909) statement. However, the presence of anterior tubular nasal opening in O. bacaila contradicts the Burne's (1909) finding. Bateson (1889), Kapoor and Ojha (1973b) advocated that anterior tubular nasal opening is characteristically present in fishes, with predominantly developed olfactory faculty. Kapoor and Ojha (1972a,b) reported that when anterior and posterior nasal openings are separated from each other by some distance, the former is invariably borne on a tube. The statement of Bateson (1889), Burne (1909), Kapoor and Ojha (1972a and 1973b), seems justified as O. bimaculatus (in present study), Cyprinus carpio, Heteropneustes fossilis and Mastacembalus armatus armatus (Sharma, 1981), Mystus vitatus (Rizvi et al., 1984) are macrostomatic fishes with anterior tubular nasal openings. O. bacaila, possesses anterior tubular nasal opening, also reveals remarkable value of olfactory sense from the point of view of ecological coefficient, calculated by area method. The concept of Kapoor and Ojha (1972a and 1973b) can not be generalised as N. chitala (of present study),

N. notopterus (Sharma, 1981) with non-tubular anterior nasal opening also exhibit macrosmatic characteristic. It can be further mentioned that in N. chitala anterior and posterior nasal openings lie at a considerable distance but anterior nasal opening is nontubular, contradicting the view of Kapoor and Ojha (1972a,b). The idea of Bateson (1889), Burne (1909) and Kapoor and Ojha (1972a, 1973b) regarding the presence of tubular anterior nasal opening in fishes with predominantly developed olfactory faculty, is in accordance with the present finding as O. bimaculatus with anterior tubular nasal openings, exhibit macrosmatic character. Although O. bacaila with tubular anterior nasal opening is eye-nose fish but the value of olfactory area is considerably higher. In N. chitala, the distance between anterior and posterior nasal opening is quite considerable and extend from the tip of snout to the eye orbit. Anterior nasal opening in N. chitala is thickly rimmed and equipped with nasal tentacle which acts as an instrument for deflecting the water to the anterior nasal opening. In living fish slight directional movement is also observed in the nasal tentacle which seems to coordinate the entry of water with the forward swimming of fish. The nasal tentacle is ventrally grooved and anteriorly expanded (Sterba, 1962). In O. bimaculatus, the tube of anterior nasal opening hangs over the upper lip and projected forwardly, taking the shape of the tip of the tusk. N. nandus bears nontubular anterior

nasal opening which is thickly rimmed and situated very close to the posterior nasal opening. This is in accordance with the finding of Burne (1909) as N. nandus exhibits poorly developed olfactory faculty bearing nontubular anterior nasal opening. In this fish it seems that unarmed anterior nasal opening is due to protrusible habit of jaws which can powerfully force water to the olfactory chamber through the anterior nasal opening. This simplification of anterior nasal opening is also due to the presence of ethmoidal and lacrymal accessory nasal sacs which can directly suck the water by their suction activity.

In O. bacaila the anterior nasal opening is in the form of a short tube which extends backwardly in the form of expanded nasal flap. This acts as a partition in between the anterior and posterior nasal openings, directing the water to the olfactory chamber through anterior nasal opening. Branson (1963) reported in Hybopsis gelida and H. aestivalis that anterior nasal opening lies on a slight protuberance and partitioned from the posterior nasal opening by a nasal flap. The nasal openings and nasal flap in O. bacaila are in accordance with Burne's (1909) nostril column IV. According to Burne (1909) and Teichmann (1954) the nasal flap is concave anteriorly, apparently serving to deflect the water current downward into the olfactory chamber, a rather general arrangement in Cyprinids. But according to present study and the findings of Sharma (1981) in C. carpio,

E. denricus, the presence of nasal flap and close situation of nasal openings is the characteristic of cyprinids.

The nasal flap in O. bacaila dips into the olfactory chamber by a curtain like extension, dividing the olfactory chamber into anterior and posterior halves. Similar condition of nasal flap is reported by Branson (1963) in H. gelida and H. aestivalis, Ojha and Kapoor (1973a) in Labeo rohita, Sharma (1981) in C. carpio. In Garra gotyla (Ojha and Kapoor, 1971) the anterior nasal opening is bounded by distinctly formed lip which is projected in the form of a duct but there is no ventral extension of nasal flap into the olfactory cavity. In Glyptothorax telchitta (Ojha and Kapoor, 1973b) the nasal openings are separated by backwardly directed nasal flap which serves to prevent the entry of water through posterior nasal opening.

In N. nandus, N. chitala, O. bimaculatus and O. bacaila, the posterior nasal opening is prominent and flushed with the general surface of the skin of the head. In all these four fishes the posterior nasal openings show considerable variation in their shape and sizes. It may be either oval (N. nandus and N. chitala) or irregular and wide (O. bimaculatus) or semilunar (O. bacaila). Burne (1909) and Malyukina et al. (1969) also found that the shape and sizes of posterior nostril vary significantly in different species. Moreover, Burne (1909) stated that Carps, Salmons and Herrings

characteristically possess crescentic posterior nasal pore. However, Garra gotyla (Ojha and Kapoor, 1971), L. rohita (Ojha and Kapoor, 1973a), C. carpio and E. denricus (Sharma, 1981) bear almost oval or roughly semicircular posterior nasal opening. Singh (1972) in Botia dario also found oval posterior nasal opening. Thus Burne's (1909) finding as crescentic posterior nasal opening in carps seems sweeping generalisation.

In O. bimaculatus posterior nasal opening lies on irregular area of integument which extends over it giving a valvular shape and shows slight movement in its surface in all the states (Swimming or stationary) of the fish. This is in agreement with the finding of Sharma (1981) in Mastacembalus armatus armatus where posterior nasal opening is covered with loose skin and continuously performing valvular movement in its surface. The posterior nasal opening in N. nandus is wide and oval. It remains covered with a skin extension, taking the shape of a valve. The posterior nasal opening in this fish is a complex structure which bears the openings of ethmoidal and lacrymal accessory sacs just below it. The posterior nasal opening in N. chitala is armoured by the head bones. Rostrally it is guarded by posterior extremities of nasal and adnasal bones whereas caudally by the anterior extremities of upper and lower longitudinal ridges of frontal. This artifact is for bearing

the pressure of speedily circulating water current which passes out through posterior nasal opening (Gregory, 1931).

The presence of valvular posterior nasal opening in N. nandus is in agreement with the finding of Burne (1909), "a valved condition (nostrils column V) is found chiefly though not solely (some siluroids) in fishes provided with accessory nasal sacs and form part of general mechanism for drawing water forcibly into the olfactory chamber through the nasal openings". Ojha and Kapoor (1972) and Kapoor and Ojha (1973), Sharma (1981) reported valvular posterior nasal opening in Wallago attu, Cynoglossus oligolepis and H. fossilis respectively but in these species the accessory nasal sacs are absent. Same is the condition in O. bimaculatus (in present study). Bateson (1889), Kyle (1899), Burne (1909), Van den Berghe (1929), Liermann (1933), Matthes (1934), Gooding (1963) suggested that posterior nasal opening is usually valvular in the fishes where two nasal openings (anterior and posterior) are situated at a considerable distance. In the present study N. chitala bears nonvalvular posterior nasal opening whereas both the openings are distantly situated but in N. nandus where both the openings are very close, posterior nasal opening is valvular.

In O. bacaila and N. nandus both the nasal openings are situated very close to each other but the posterior is considerably larger than the anterior. Johnsen and Brown

(1962) in Sabastodes melanops, Ojha and Kapoor (1974) in Sisor rhabdophorus and Rahmani (1979) in Corax oblongus reported that whenever the two apertures are closely situated, their size discrepancy become minimum. Contrary to this O. bacaila (in present study), C. carpio and E. denricus (Sharma, 1981) possess closely situated nasal openings but they exhibit great discrepancy in their size. In O. bacaila and N. nandus the posterior nasal opening is remarkably wide, covering most part of the olfactory chamber through which lamellae can be peeped into. Branson (1963) reported considerably wide posterior nasal opening in H. gelida and H. aestivalis. Rahmani (1979) observed poorly developed nasal flap in posterior nasal opening of Ehippus orbis but rarely found in the form of tube. Tubular posterior nasal opening is only observed by Burne (1909) in Muraena helena, M. tigrina and Kapoor and Ojha (1972a) in Muraena undulata. Rahmani (1979) was of the view that all these species of genus Muraena are same and wrongly described in the form of different species by Burne (1909).

The author is of the opinion that in most fishes anterior nasal opening is situated above the surface of the head, projecting forward and upward either in the form of thick rim, or border or tube or thickened margin or lip or in the form of some protuberance but posterior is generally flushed with the surface of the skin of head. This may be a device for currenting the water circulation unidirectionally

which can easily enter through anterior nasal opening and exit through posterior. The olfactory epithelium always remains in contact with water as those of gills which is facilitated by creating constant circulation of water through olfactory chamber. The placement of anterior and posterior nasal opening is so arranged that former is having elevated position while the latter flushed with the general surface of head. Such arrangement of both the nasal openings brings about the entry of water from anterior and its exit from the posterior synchronously with the forward progression of fish and jaw movement.

According to Doving and Thommesen (1977) the olfactory passage in fishes is diagrammatically divided into anterior vestibule and posterior gallery. Both these divisions remain connected with corridors which are the interlamellar spaces in between the lamellae of a rosette. On the basis of above division Doving et al. (1977) demonstrated that an unidirectional water current passes from vestibule to gallery via corridors. In view of the mechanism employed for the transportation of water through olfactory chamber, fishes can be grouped as Isosmates and Cyclosmates (Doving et al., 1977; Doving and Thommesen, 1977). In the former group, they placed carps, roaches, cat fishes, eels and rocklings where only ciliary action is responsible for the creation of water current while in latter compression and

expansion of accessory nasal sacs cause the water to circulate through the olfactory chamber. Doving et al. (1977) also mentioned that in cyclosmate fishes, the olfactory passage is not divided into vestibule and gallery. In the present study O. bacaila, without accessory sacs and N. nandus with accessory sacs exhibit almost similar type of olfactory passages whereas according to Doving et al. (1977) former is isosmate and latter cyclosmate. In both the fishes olfactory chamber is confined to a short area on the head. In O. bacaila olfactory chamber is provided with anterior tubular and posterior semilunar nasal openings, leaving no space for the formation of vestibule and gallery. The author is of the opinion that division of olfactory passage, as mentioned by Doving et al. (1977) and Doving and Thommesen (1977), is based on the morphological structure of the olfactory chamber in accordance to the shape of the head and not on the basis of the presence or absence of the accessory nasal sacs. O. bimaculatus and N. chitala are provided with well defined vestibule, corridors and gallery. In both these fishes accessory sacs are absent.

In the present study it is advocated that elongated olfactory chamber exhibits well defined distinction of vestibule, corridors and gallery. This can be confirmed with the present study of O. bimaculatus, N. chitala and in H. fossilis (Sharma, 1981).

Keeping in mind the idea of Doving et al. (1977) and Doving and Thomesen (1977) the author has evolved the term "mesosmates" and put N. chitala and O. bimaculatus under this group. In view of present study mesosmate fishes are devoid of accessory nasal sacs but provided with a larger lamellaeless area which assists in maintaining the continuity of water circulation through the olfactory chamber. The placement of N. nandus, under the category of cyclosmate fishes is in accordance with the findings of Doving et al. (1977) and Doving and Thommesen (1977) where well developed accessory nasal sacs are present, with the result vestibule and gallery become insignificant.

#### The olfactory rosette:

The organs of olfaction are represented by a pair of olfactory sacs (chambers) which in sharks and rays located on the ventral surface of the head. The olfactory chambers are lined by the olfactory epithelium which is raised from the floor of the organ into a complicated series of folds or lamellae to make a rosette (Hara, 1975). The shape of the olfactory rosette varies greatly in different species. Bateson (1889) distinguished four types of rosettes (i) in skates and dog fishes lamellae are arranged in a radiating manner like the septa of an orange, (ii) in conger and eel the lamellae are arranged in two rows, on either side of the central raphe, (iii) the lamellae are fitted together in a

radiating manner forming a convex eminence in the olfactory chamber, it is either circular (Cottus, Motella mustela etc.) or elliptical (mackerel etc.), such type of rosettes are most common in fishes, (iv) lamellae are arranged in a single row generally parallel to the long axis of the body of fish, the raphe is absent e.g., Solea, Pleuronectes etc.

Burne (1909) reported three types of olfactory rosette: oval (in most of the fishes), rounded (in Esox), an elongated (in Anquilla). Fishes with rounded rosette normally have a few lamellae and usually show little response to the sense of olfaction. Species with oval rosette are most common but fishes with elongated rosette show dominantly developed olfactory faculty. Among fifty two genera, studied by Burne (1909), the oval rosette was present in thirty two genera, elongated in seven and circular and parallel rosette in three each. In few genera like Belone, Hemirhamphus, Exocoetus and Lophius, the rosette was found absent (Burne, 1909).

Teichmann (1954) has attempted to show that the oval (Bateson's, 1889 rosette type 3; Burne's, 1909 rosette column I), circular (Bateson's, 1889 rosette type 3; Burne's, 1909 rosette column III) and elongated (Bateson's, 1889 rosette type 2; Burne's, 1909 rosette column II) rosettes can be linked with his own (Teichmann, 1954) first, second and third group of the eye-nose, eye and nose fishes

respectively. Teichmann (1954) explained that fishes with oval rosette possess equally developed eye and nose faculty, circular rosette with predominantly developed optic faculty and elongated rosette with predominantly developed olfactory faculty.

The position of the olfactory chamber and the shape of olfactory rosette varies greatly in all the four fishes, selected for this research work. The olfactory chamber is close to eye orbit (N. nandus), close to snout (O. bimaculatus), in between the snout and eye orbit (O. bacaila) and extending from snout to eye orbit (N. chitala). In N. chitala the olfactory chamber is very much specialised for considerably broad and long olfactory rosette. The snout of N. chitala, with respect to accommodate such rosette, takes a sharp curve, leading to the elongation of snout unlike N. notopterus. According to Hara (1975) eels and morays have large olfactory chamber on the dorsal surface of the head, extending from eye orbit to snout. Similarly M. armatus armatus is provided with exceptionally elongated snout wherein olfactory chamber is of the same length and width (Bhargava, 1959; Sharma, 1981). Kapoor and Ojha (1972a) reported in W. attu that olfactory chamber occupies dorsal position of the head but lies close to snout. Kapoor and Ojha (1972, 1973) also reported in Muraena undulata and Channa punctatus that olfactory chamber extends from eye orbit to snout. Branson (1963) in H. gelida

and H. aestivalis, Ojha and Kapoor (1971, 1973) in Garra gotyla and L. rohita, Sharma (1981) in C. carpio and E. denricus, in present study O. bacaila found the olfactory chamber close to eye orbit than the snout and all these species belong to group Cyprinidae. Therefore, author is of the opinion that in carps, it is generally situated close to eye but cat fishes like W. attu (Ojha and Kapoor, 1972a), H. fossilis (Sharma, 1981) and O. bimaculatus (in present study) possess olfactory chamber close to snout. The position of olfactory chamber is generally modified with the elongation of jaws as reported in eels and Morays (Hara, 1975), M. undulata (Kapoor and Ojha, 1972) and M. armatus armatus (Bhargava, 1959; Sharma, 1981) and subjected to its elongation from the tip of snout to the eye orbit. Similar is the condition in N. chitala (in present study). N. nandus is a highly predaceous fish, provided with widely extensible jaws, with the result olfactory chamber is modified accordingly and substituted with the presence of highly extensible accessory nasal sacs. As buccal apparatus of this fish is vigorously operable and premaxilla occupies a wider frontal part, subsequently olfactory chamber is pushed back close to eye orbit in a contracting manner.

The olfactory rosettes, in all the four fishes under present study, are subject to great modification with the shape and size of olfactory chamber. It is rounded (in O. bacaila), elongated and roughly leaf shaped (in O. bimacu-

latus), boat shaped (in N. chitala) and quadrangular (in N. nandus). Due to elevated adnasals and nasal in N. chitala the olfactory chamber acquires a considerable depth and elongation, with the result rosette within it becomes specialised and takes a shape of boat. In N. nandus the rosette is quadrangular restricted close to eye due to the protrusible nature of jaws.

On the basis of categorization of Bateson (1889), Burne (1909) and Teichmann (1954) the roughly leaf and boat shaped elongated rosettes of O. bimaculatus and N. chitala can be placed under Bateson's (1889) rosette type 2; Burne's (1909) rosette column II and Teichmann's (1954) group III. Rounded rosette of O. bacaila under Bateson's (1889) rosette type 3, Burne's (1909) rosette column III and Teichmann's (1954) group II. The rosette of N. nandus is quadrangular and so much compressed, with most of its part lamellaeless and peculiarly substituted with well developed accessory nasal sacs. Such a rosette can not be fit in any of the categories of Bateson (1889), Burne (1909) and Teichmann (1954). The placement of the rosette of N. chitala in the above categorization is not very much justified as it has acquired a considerable height with the erection of nasal and adnasal bones on both the lateral sides of the rosette.

Kapoor and Ojha (1971b) and Ojha and Kapoor (1973b) reported oval rosette in Garra gotyla and Glyptothorax

telchitta, having predominantly developed olfactory faculty. Bertmar (1972b) suggested that both macrosmatic as well as microsmatic fishes may possess oval rosette and thus shape has no concern with the efficiency of the olfactory rosette.

In the present study N. nandus with quadrangular rosette reveals poorly developed olfactory faculty but N. chitala with boat shaped elongated rosette is having excessively developed olfactory faculty. O. bimaculatus and O. bacaila also exhibit well developed olfactory faculty. The optic faculty of these two fishes and N. chitala is also considerably developed which may be an addition in the efficiency of these fishes. The olfactory faculty in N. nandus is morphologically giving an idea of its regression which suits to its predaceous habit as it visually targets the fish and other prey for engulfing them within its protrusible jaws. Olfactory rosette is supplemented with accessory nasal sacs which may bear the pressure of strong water current during protruding activity of jaws. N. nandus can swallow fishes of half of its own size which can only be possible by visually objecting them. Although O. bacaila numerically shows greater development in olfactory faculty but the area of two retinae is also relatively not as much different as in other fishes of the present investigation. Therefore, this fish may be put in the category of eye-nose fish where both the faculties are almost equally developed

and helping the fish in discharging its activities of defence, schooling, courtship and feeding etc.

The rosette, in the fishes of present study except N. nandus, is provided with anteroposterior thickening, called raphe. It is short and broad in O. bacaila, elongated and thin in N. chitala and O. bimaculatus. The raphe of O. bacaila histologically reveals similar structure as those of other lamellae. Hence this may be treated as central lamella and acts as an instrument for permitting the attachment of all the lamellae. The raphe of O. bimaculatus and N. chitala exhibit different histological picture as compared to lamellae. In both the fishes the raphe is made up of nonciliated single layered columnar and basal cells. The vascular and connective tissue etc. supply is through raphe. In O. bacaila, vascular, connective tissue and other supplies are in all the lamellae and raphe reaching from one point of the rosette and diverging in all the lamellae uniformly. Mucous secretory cells are also rarely visible in the raphe of O. bacaila. Branson (1963) in H. gelida and H. aestivalis recalled it as central lamella, possessing ciliated and sensory cells but Kapoor and Ojha (1973) in L. rohita described it as nonsensory, nonciliated and nonsecretory structure, permitting the attachment to other radial lamellae. Sharma (1981) reported that the raphe in E. denricus is histologically identical to its lamellae but in C. carpio, H. fossilis and N. notopterus, it differs in histological

composition with their lamellae. The raphe is observed by various workers (Burne, 1909; Sheldon, 1911; Tret'yakov, 1939; Teichmann, 1954). Burne (1909) reported the presence of raphe in forty two fishes out of fifty two. The author is of the opinion that raphe may be a modified lamella or it may be exclusively made up of the thickening of the floor of olfactory chamber. In both the conditions it permits attachment to the lamellae in different ways. It may be further concluded that fishes having elongated rosette may possess raphe as the thickening of the floor of olfactory chamber but in case of circular or oval rosette the raphe may be a modified lamella.

It is observed that rapheless fishes possess comparatively lesser number of lamellae as in Xenentodon cancila, one lamella (Singh, 1972); Sabastodes melanops, thirty lamellae (Johnson and Brown, 1962); Sea trout, fourteen to sixteen lamellae (Bertmar, 1972); Channa punctatus, twelve to twenty four lamellae (Kapoor and Ojha, 1973a); Anabas testudineus, seven to ten lamellae (Rahmani and Khan, 1977); Tetradon patoca, two olfactory flaps (Rizvi and Khan, 1980) and N. nandus, seven to ten lamellae (in present study).

The author is of the view that rapheless fishes possess regressed olfactory organ as compared to the fishes bearing raphe. Although some of the fishes having raphe

also show microsmatic character, however, they are not as regressed as the rapheless fishes. Sharma (1981) reported microsmatic E. denricus but it is not as regressed as the fish devoid of raphe. Raped fishes in majority exhibit macrosmatic character which indicates that raphe is an additional structure, increases the olfactory surface and permits the attachment to the lamellae. It also facilitates proper reception of sensation through the water current.

The number, location, form and degree of development of folds (lamellae) in olfactory rosette of bony fishes vary significantly (Burne, 1909; Liermann, 1933; Hara, 1975; Kapoor and Ojha, 1972, 1973). The largest number of lamellae was observed in Haplopagrus quentheri (Pfeiffer, 1964) where olfactory rosette is provided with 230 lamellae in a fish 480 mm of length. The olfactory rosette of Barbot is provided with more than 50 lamellae (Teichmann, 1954), Japanese eel (Anguilla anguilla) with 70 lamellae (Shibuya, 1960), Bream 34-36 (Bedrova, 1962), H. fossilis with 46-64, N. notopterus 58-80, C. carpio 24-36 and M. armatus armatus with 154-240 lamellae (Sharma, 1981). In each case there is a successive increase in the number of lamellae as the size of fishes increases.

In the present study the rosette of O. bacaila bears 22-32, O. bimaculatus 64-104, N. nandus 7-10 and N. chitala 76-152 lamellae. In all these fishes lamellae

show a trend of successive increase in their number with the growth of a fish.

Yamamoto and Ueda (1977, 1978a,b,c,d,e) reported that the arrangement of lamellae in a rosette is either in two rows on each side of the raphe or in a single row, arranged parallel to the long axis of the body or coming out from a single point. Kapoor and Ojha (1973) in Channa punctatus and Rahmani and Khan (1977) in Anabas testudineus reported the parallel arrangement of lamellae in a single row. Burne (1909), Teichmann (1934), Branson (1963), Ojha and Kapoor (1971, 1973a,b, 1974) and Kapoor and Ojha (1972, 1973), Sharma (1981) observed that most of the fishes bear two rows of lamellae on either side of raphe.

In present study most accepted arrangement of lamellae in two rows on either side of raphe is observed in O. bacaila, O. bimaculatus and N. chitala but in N. nandus the arrangement of lamellae is of peculiar type, roughly in the form of lotus petals. In this fish quadrangular rosette is befitted in the olfactory chamber but bears lamellae on its anterior side, leaving posterior part lamellaeless. The lamellae in all the forms of present study are so arranged that interlamellar spaces are maintained in between the two lamellae and permit the water circulation through them.

The number of lamellae in N. chitala is considerably higher ranging upto 152 in a fish of 631 mm total length and O. bimaculatus upto 104 in a fish of 273 mm total length. Sharma (1981) reported highest 240 lamellae in M. armatus armatus, prior to him Pfeiffer (1964) reported 230 lamellae in Haplopagrus quentheri. The author is of the opinion that fishes which attain greater length may bear large number of lamellae with considerable variation in number of lamellae with regards to the length. In present study O. bimaculatus and N. chitala show greater range in their lengths, with the result the number of lamellae increases remarkably. This finding is in accordance with Sharma (1981) in M. armatus armatus and Pfeiffer (1964) in Haplopagrus quentheri.

The author observed that the lamellae show a clear cut increase in their number with the total length of all the fishes in present investigation and it is an agreement with the findings of Bateson (1889), Burne (1909), Liermann (1933), Teichmann (1954), Eaton (1956), Johnson and Brown (1966), Pfeiffer (1963, 1964), Kleerekopper (1969), Ojha and Kapoor (1971, 1972, 1973a,b, 1974), Kapoor and Ojha (1972a, 1973a,b), Hara (1975), Doving and Thommesen (1977), Sharma (1981). However, Pfeiffer (1962) in Onchorhyncus reported that the number of transverse lamellae increases with the growth of the fish upto a certain extent and then it remains relatively constant. Rahmani and Khan (1977) found that in adult A. testudineus the number of lamellae varies from 7-10 and no

correlation can be established between the number of lamellae and the size of fish. Davitsyna (1972) stated that the number of lamellae remains relatively constant and is a characteristic of each species. Consequently, the enlargement of receptor surface is at the expense of an increase in the area of lamellae and not in their number. The author is of the opinion that increase in the number of lamellae with the size of fish is a characteristic of olfactory rosette but after attaining an optimum length or size, the number of lamellae either becomes constant or varies marginally.

Burne (1909) reported "considerable differences are apparent in the shape of individual laminae of the rosette. Starting from the type presented in Gaddus as a centre (rosette, column V), one line of variation leads by the suppression of the peripheral part of lamina and the exaggeration of the linguiform process (rosette, column VI) to a claw like shape which is peculiar characteristic of the rosette of Salmonidae and Clupeidae".

In present work the lamellae of O. bimaculatus and N. chitala bear linguiform processes, which are more prominent and occupy dorsomedian region of the lamellae in latter while in former they are in the form of thick protuberances, having dorsomedian position slightly towards the distal ends. The author is in agreement with the finding of Burne (1909) that they come out with the result of suppression of the lamellae and subsequently exaggerating in the form of

linguiform processes. The lamellae of N. chitala, with the result of suppression and exaggeration, take the shape of plough while in O. bimaculatus in the form of saw. In O. bacaila the lamellae are subjected to sharp suppression on their dorsal surface which make them concave uniformly and therefore, the question of formation of linguiform processes does not arise. In N. nandus the lamellae directly emerge out from the floor of olfactory surface and thus exhibit no trend of suppression and exaggeration. Linguiform process, termed as "thumb" by Doving et al. (1977), divides olfactory chamber into central and peripheral channels. In N. chitala and O. bimaculatus linguiform process divides the olfactory chamber into central and peripheral channels but in O. bacaila it is undivided due to absence of linguiform process. In N. nandus there is no such formation of central cavity of olfactory chamber because it is rapheless and devoid of linguiform process.

Doving et al. (1977) diagrammatically divided the olfactory passage into vestibule, gallery and inbetween these two, interlamellar spaces called corridors where ciliary movement instruments the water current unidirectionally. Doving and Thommesen (1977) on the basis of water circulation through olfactory organ divided the fishes as isosmates and cyclosmates. The former group of fishes operates the water circulation through the olfactory chamber by the beating of cilia while in latter group with the help of

accessory nasal sacs. In accordance with Doving et al. (1977) the diagrammatic division of olfactory passage in N. chitala and O. bimaculatus can be distinctly identified as gallery, corridors and vestibule. In former fish gallery is prominent, constructed with the confluence of lamellaeless area of olfactory rosette with the posterior nasal opening whereas in latter vestibule is more prominent because of the tubular anterior nasal opening. The corridors in both the fishes are more prominent and ciliated, having a considerable depth in N. chitala due to the elevated posture of the olfactory rosette while in O. bimaculatus they are of moderate depth. O. bacaila possesses insignificant vestibule and gallery because of the restricted position of olfactory chamber and extraordinary wide posterior nasal opening, permitting constant water touch with the lamellae, and keeping them permanently exposed to the medium. The corridors in this fish are present and ciliation is observed in inter-lamellar spaces. In N. nandus the olfactory rosette is pushed backwardly due to protrusible activity of jaws, consequently, the olfactory passage becomes contracted and supplemented with the accessory nasal sacs. In view of the classification of Doving and Thommesen (1977) N. nandus falls in the category of Cyclosmate whereas O. bacaila, N. chitala and O. bimaculatus under isosmate. In the present study N. chitala and O. bimaculatus are put under the category of mesosmates as

they are provided with lamellaeless area, compensating the absence of accessory nasal sacs. In former the lamellaeless area of rosette in confluence with posterior nasal opening plays an important role in drawing water to the olfactory chamber whereas in latter it surrounds the rosette all around and maintains continuity of water circulation.

#### Ecological coefficient:

In all animals except the most primitive ones, behaviour is largely dependent on a highly organised nervous system. The topography of brain has been done to study the relative size of the olfactory bulbs, lobes and olfactory tectum which reflect the degree of development of olfactory and visual reception. Davis and Miller (1967) also observed that since the development of sensory lobes (or bulbs) reflects hypertrophy of peripheral sensory mechanism, inference about the functional significance of these modalities may be made with reasonable confidence. In Carpsucker, Carpiodes velifer (Miller and Evans, 1965) for example, due to great development of taste buds in mouth and palatal organ, the vagal lobes are large. On the other hand Evans (1935, 1952) reported that in gadidae, cyprinidae and catostomidae where external taste buds are numerous, the facial lobes become enlarged. Thus the relative development of the different lobes of brain may reveal to some extent the degree of development of different faculties. Therefore, macrosmatic

fishes must have large olfactory lobes and bulbs but have poorly developed optic lobes while microsmatic ones must have just reverse condition.

The prosencephalon is related to olfaction, mesencephalon to vision and rhombencephalon to taste, equilibrium and lateral line system (Parker and Haswell, 1951; Lagler et al., 1962). Nevertheless, the brain of teleosts has undergone a great modification. The dipnoan's brain is very similar to those of elasmobranchs whereas in actinopterygii the fore brain architecture is specific and shared by no other vertebrate. The brain of crossopterygii is intermediate (Hildebrand, 1974).

The noteworthy feature in some fishes is the location of olfactory bulb which is far away from the brain and lies near the olfactory rosette. Such condition is known as pedunculate, conversely, numerous fishes have sessile olfactory bulb i.e. the olfactory bulb is attached with the fore brain.

In the present investigation the olfactory bulb is sessile in N. nandus but pedunculate in N. chitala, Q. bimaculatus and Q. bacaila. Sessile olfactory bulb has been reported by Marshall (1967) in Cyclothone microdone, Cyema atrum etc., Hara (1975) in Anquilla, Esox, Salmo, Schnitzlein (1977) in Anquilla japonica, Conger myriaster and Muraenesox cinereus, Rahmani and Khan (1977) in

A. testudineus, Rizvi and Khan (1980) in Tetradon patoca and Sharma (1981) in M. armatus armatus. Hara (1975) was of the opinion that most of the teleosts have sessile type of olfactory bulb. However, many fishes for example Selachi (Johnston, 1911; Malyukina et al., 1969), Corydora paliatus (Miller, 1940), Carassius auratus (Schnitzlein, 1964), gadidae (Devitsyna, 1972), Garra gotyla (Ojha and Kapoor, 1971), W. attu (Ojha and Kapoor, 1972), L. rohita (Ojha and Kapoor, 1973a), Galeichthyes felis (Morgan, 1975), H. fossilis, C. carpio and N. notopterus (Sharma, 1981) have pedunculate olfactory bulb. Hara (1975) reported intermediate position of bulb between nose and fore brain in Raniceps raninus, Gymnothrax kidaco and Coryphaena hippurus; Sharma (1981) reported the same intermediate position in E. denricus.

The relationship between sensitivity of olfaction and location of bulb has not been differentiated (Malyukina et al., 1969). The present findings reveal that such relationship exists between microsmatic and macrosmatic forms with respect to sessile and pedunculate conditions of olfactory bulb. N. nandus with sessile olfactory bulb exhibits microsmatic character whereas other fishes with pedunculate or intermediate position of olfactory bulb show macrosmatic nature of olfactory sensation. Malyukina's et al. (1969) observation further supplied by Marshall's (1967) researches on bathypelagic fishes. The males of most

bathypelagic fishes have large olfactory organ (macrosmatic condition) but females have small or regressed olfactory organ (microsmatic condition). Same findings were reported by Waghray (1986) in electric ray, Narcine timelele where sexual dimorphism is observed. In both the sexes sessile bulb is reported.

Shifting of olfactory bulb, close to the rosette (pedunculate condition) may be considered as an enhancement in the device of the reception of olfactory sensation more efficiently than the sessile one. This can be justified by observing macrosmatic nature of N. chitala, O. bimaculatus and O. bacaila (mesosmatic) bearing pedunculate bulb.

Ecological coefficients calculated by relative lengths of telencephalon, mesencephalon and by the areas of both the rosettes and retinae, give distinctive results which can illustrate microsmatic, macrosmatic and eye-nose fishes (Tables 1-4). In O. bimaculatus and N. chitala the area of two rosettes is remarkably higher than that of the two retinae and subsequently the value of telencephalon plus olfactory bulb stood considerably dominating over the mesencephalon discriminating these as macrosmatic fishes. N. nandus gives an idea of its microsmatic nature as the value of two retinae and those of mesencephalon is higher than those of two rosettes and telencephalon. With regards the calculation of sensitivity from the point of view of area and brain lobe

method, O. bacaila exhibits no major difference in the values of both the faculties. Hence this fish may be put under the category of eye-nose fish.

N. nandus shows predominantly developed optic faculty which can be correlated with its highly predaceous nature, preying on small cyprinids and visually dash out to capture them. Hence N. nandus is a microsmatic fish totally depend on optic faculty in discharging the activities required for the successful existence of this fish.

N. chitala with well developed olfactory faculty also utilizes vision in locating its prey in the depth of water as it is a bottom feeder. This heavy bodied fish becomes more active during night, mainly operating sense of olfaction in discharging the vital functions.

O. bimaculatus is a carnivorous fish but feeds on insects and their larvae where olfactory sense is required significantly for the location of these deep water micro-organisms.

O. bacaila is a surface feeder, feeds on mosquito larvae and equally utilizing both the faculties for the capture of the food and discharging other life activities justifying its position as eye-nose fish.

The author is of the opinion that irrespective of macrosmatic, eye-nose and microsmatic nature of fishes under

present investigation, the role of optic faculty can not be ignored, though its degree of efficiency with respect to olfactory sensitivity may varies. Except for the fishes of abbyssopelagic zone of the sea, dark caves, very turbid water where vision is minimum or nil, most of the fishes utilize both vision and olfaction in performing the functions required for their existence.

The olfactory organ of fishes has a low threshold (Teichmann, 1959; Kleere-Koper, 1969; Hara, 1973). The food source or a companion gives off its odour which diffuses or diminishes with the distance in accordance with something like inverse law of gas diffusion. The concentration of odour falls off rapidly with distance from the producer. When the receiver receives odour, it becomes excited and follows the odour gradient. If the receiver is very far off where the gradient has labelled, the excitement and increased activity of receiver might bring it nearer to the source where the gradient may be useable. Once the receiver is near the source of odour, its vision becomes more important. Thus whatsoever the condition of fishes may be (microsmatic, macrosmatic and intermediate) both vision and olfaction complement each other and play an important role in their behaviour.

### The water circulation:

In all the four fishes of present investigation namely N. nandus, N. chitala, O. bimaculatus and O. bacaila water enters the olfactory chamber through anterior nasal opening and expelled out through the posterior. This explains the unidirectional flow of water.

The author thinks that water flow is always from anterior to posterior direction in the olfactory chamber irrespective of architectural differences of the two nasal openings. Doving et al. (1977) reported that the direction of ciliary beat is consistent with the direction of water current i.e. the cilia beat from anterior to posterior direction of olfactory chamber. Eaton (1956), Johnson and Brown (1962), Kapoor and Ojha (1973a) have reported the entry of water current through both the nasal openings but it is expelled out through the posterior. Kapoor and Ojha (1973a), Rahmani and Khan (1977) mentioned that water can enter and exit through both the openings.

The constant beating of cilia creates the water current from anterior to posterior direction and the entry of water through posterior nasal opening will disturb the regular ciliary movement and ultimately the water current will be distorted. The histological observations in all the four fishes reveal the ciliation in the lamellar epithelium

and it is inclined in one direction, presenting a concept of unidirectional ciliary movement.

In addition to unidirectional ciliary movement, the anterior nasal opening is commonly placed forward and slightly above the surface of the head. Similar is the finding in all the fishes of present study. The anterior nasal opening is equipped either with thickened border or tube or tentacle or some other form which is in accordance with the concept that it is meant for receiving the water current during the forward movement and nonswimming state of the fish. The posterior nasal opening is wide in most of the fishes as compared to the anterior and it can conveniently release the water out. O. bimaculatus and N. nandus possess valved posterior nasal openings which can only permit the exit of water current. N. chitala and O. bacaila are provided with nonvalvular posterior nasal openings, permitting expulsion of water without any hinderance.

N. nandus bears well developed ethmoidal and lacrymal accessory nasal sacs in relation to ethmoid and lacrymal bones. These sacs open by their separate openings underneath the valvular posterior nasal opening. It is a highly predaceous fish and capable of swallowing the fish of half of its own size, with the result strong jaw operation is reported. In this fish water current is created during

its forward progression, protrusible activity of jaws and opercular movement. The presence of accessory nasal sacs in N. nandus is an adaptation to its predaceous, active life and for accommodating enormous water. This is an agreement with Doving and Thommesen (1977) and Doving et al. (1977). Though O. bimaculatus and N. chitala are devoid of accessory nasal sacs, however, they are provided with some lamellaeless area in the rosette which maintains the grid of water circulation. O. bacaila is having short olfactory passage with wide posterior nasal opening which allows constant contact of water with the olfactory epithelium. In isosmate fishes the accessory nasal sacs are absent but they are provided with lamellaeless area which maintains continuous circulation of water through olfactory chamber. The residue of water always remains in the lamellaeless area in isosmate and in accessory sacs in cyclosmate fishes.

Valves in posterior nasal openings have been reported in Cod and Navaga (Devitsyna, 1972), Moraena undulata (Kapeer and Ojha, 1972a), W. attu (Ojha and Kapoor, 1972), G. telchitta (Ojha and Kapoor, 1973b), H. fossilis, M. armatus armatus (Sharma, 1981). The valved condition of posterior nasal opening is observed in O. bimaculatus and N. nandus (in present study). The fishes which do not have valve possess small posterior nasal openings, for example, C. punctatus (Kapeer and Ojha, 1973b), Clarius lazera (Burne, 1909),

Anquilla anquilla (Teichmann, 1954) but present study contradicts these findings as nonvalvular posterior nasal opening in O. bacaila is remarkably wide. Similar finding was reported in C. carpio and E. denricus (Sharma, 1981).

When the fish swims in forward direction, water current is obviously created anteroposteriorly. The position of anterior nasal opening is always projected on the surface of snout either in the form of tube or border or rim or tentacle which may be an architectural adaptation for getting the water in the olfactory chamber of fish.

Garra gotyla (Kapoor and Ojha, 1971), Bagarius bagarius and Botia dario (Singh, 1972), L. rohita (Ojha and Kapoor, 1973a) possess hood like structure which helps in deflecting the water into the anterior nasal opening. Burne (1909), Liermann (1933), Teichmann (1954), Johnson and Brown (1962), Gooding (1963), Pfeiffer (1962) have also reported the presence of hood or nasal flap between anterior and posterior nasal pores. In present fishes, O. bacaila possesses short tube whose posterior half is broadly elevated in the form of a nasal flap in between anterior and posterior nasal openings, helps in directing the water to the anterior nasal opening during forward progression of the fish. In N. chitala the water current is deflected to the anterior nasal opening by nasal tentacle (Sterba, 1972) which is forwardly directed and ventrally grooved, raised from the thickened border of anterior nasal opening.

According to Doving et al. (1977) fishes are put under the category of cyclosmates and isosmates with respect to their course of water circulation. In the former, olfactory chamber is provided with well developed accessory nasal sacs which help in drawing the water through the olfactory chamber but in latter the water current is created by the ciliary movement of the lamellae. N. nandus falls under the category of cyclosmate but O. bacaila, O. bimaculatus and N. chitala under isosmate fishes. The author is of the opinion that in all the fishes olfactory mucosa is ciliated which brings about the water current through the olfactory chamber and the accessory nasal sacs may be an additional device. Doving and Thommesen (1977) diagrammatically divided the olfactory passage into vestibule, corridors and gallery. The corridors are interlamellar spaces, richly supplied with cilia in all the four fishes of present study. The vestibule and gallery are well defined in O. bimaculatus and N. chitala but with the restriction in the size of the olfactory chamber, the vestibule and gallery become less prominent in O. bacaila and N. nandus.

Although O. bimaculatus and N. chitala are isosmate fishes, however, their olfactory rosettes are provided with some sort of lamellaeless area which maintains the continuity of water circulation. The former is provided with a girdle like lamellaeless area, encircling it all around the periphery

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whereas in latter it is in confluence with the posterior nasal opening. O. bacaila bears well exposed olfactory rosette through a wide posterior nasal opening. The author is of the view that lamellaeless areas in O. bimaculatus and N. chitala compensate the absence of accessory nasal sacs.

In N. chitala and O. bimaculatus the course of water circulation is longest because of the elongated olfactory chamber. In former it covers the area from snout to optic region and the posture of olfactory rosette is exceptionally elevated due to the presence of nasal and adnasal bones. In both the fishes water is drawn into the anterior nasal opening either by nasal tube or tentacle (as the case may be). In N. chitala the lamellaeless area in confluence with the posterior nasal opening creates suction of water, synchronously with the opercular movement and yawning of the fish. This leads the circulation of water through central and peripheral channels of the olfactory rosette and properly passes through the interlamellar spaces. It is ultimately expelled out through the posterior nasal opening. In O. bimaculatus water enters through the anterior tubular nasal opening and circulates through central and peripheral channels of olfactory cavity and through the lamellaeless area, finally passes out through the posterior nasal opening. In both these fishes residual water is always present in their lamellaeless areas which maintain the

continuity of water circulation. The mucosa is densely ciliated and linguiform process inclining anteroposteriorly, operate the water current effectively and ensures proper involvement of water with the olfactory surface. In N. nandus water is effectively circulated by the expansion and contraction of accessory nasal sacs, synchronously with jaw movement. In O. bacaila the olfactory passage is shortest because of the presence of wide posterior nasal opening which permits constant exposure of olfactory lamellae to the water in all the states (stationary or moving). The water circulation in this fish is unidirectional, enters through anterior and passes out from posterior nasal opening.

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DISCUSSION OF HISTOLOGY

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### Histology:

The general pattern of olfactory epithelium of vertebrates has been studied by Hopkins (1926), Kolmer (1927), Allison (1953), Bloom (1954), Le Gros Clark (1957), De Lorenzo (1957), Ottoson (1963), Porter and Bonneville (1964), Frisch (1967), Moulton and Beidler (1967), Whelan et al. (1986) and they described that it comprises of receptor cells intermingled with supporting cells. The other cellular components and fine structure of the olfactory epithelium have been worked out in number of fishes by Trujillo-Ceno'z (1961), Bannister (1965), Bronshtein and Ivanov (1965), Vinnikov (1966), Wilson and Westerman (1967), Gemne and Doving (1969), Kleerekoper (1969), Ojha and Kapeer (1973), Kapeer and Ojha (1974), Hara (1973), Yamamoto and Ueda (1977, 1978a,b,c,d,e,f), Zeiske et al. (1979), Theisen et al. (1980), Rahmani and Khan (1980), Sharma (1981), Singh and Singh (1986) and Doroshenko and Motavkin (1987). It is commonly observed that the basic plan of olfactory epithelium of fish exhibits no fundamental variation from general vertebrate pattern. The lamellae of fishes consist of two main layers: the outer mucosa, consists of supporting, secretory and sensory cellular components and the inner central core or submucosa with nutritive and supporting components. The relative thickness of mucosa and submucosa varies greatly from fish to fish and sometimes in the rosettes of the same fish. The basement membrane stands

as partition in between mucosa and submucosa and serves as the medium for the exchange of nutritional and nervous supplies.

In the present histological study of the olfactory epithelium of N. nandus, O. bimaculatus, N. chitala and O. bacaila, similar cellular organisation is observed with individual variation in the arrangement and shape of different cell types. N. nandus and O. bimaculatus show greater cellular activity in the olfactory epithelium discriminating it as transitional and nontransitional epithelium.

The transitional condition of the olfactory epithelium in N. nandus is due to the flow of basal cells towards its periphery consequently, displacing the surrounding cellular components. This leads to depressions in the shape of flask, funnel, vacuole and tubule. Conversely cuneiform, filiform, fungiform, hillock and minor elevations are resulted on the general olfactory surface. O. bacaila exhibits cellular activity on the olfactory surface which results swelling, narrowing, terminal curving, knobbing clubbing and trification in the lamellae. The olfactory epithelium of N. chitala is clearly distinguished into supporting and sensory zones. Doroshenko and Motavkin (1987) reported receptory and indifferent epithelii. In O. bimaculatus very few number of posterior lamellae are in old and worn out

state, having enormously developed body and loose cellular organisation. Sharma (1981) observed zonation and transitional state of olfactory epithelium in H. fossilis and C. carpio.

#### The supporting cells:

According to Ojha and Kapoor (1973) the supporting cell bears 8-12 cilia implanted on the basal body. In the present study the olfactory epithelium of N. chitala and O. bimaculatus is provided with ciliated and nonciliated supporting cells, arranged in well demarcated zones. In N. nandus ciliated supporting cells are present in the uniform olfactory epithelium but in its transitional condition they are nonciliated and having short body. In O. bacaila the supporting cells are mostly ciliated. Hopkins (1926), Kolmer (1927), Allison (1953), Branson (1963), Watling and Hillemann (1964), Bannister (1965), Ojha and Kapoor (1974) described only ciliated supporting cells in the olfactory epithelium of fishes. Holl (1965), Bertmar (1972), Rahmani and Khan (1980), Sharma (1981), Singh and Singh (1986) reported the presence of ciliated and nonciliated supporting cells in the olfactory epithelium of some teleosts. Bertmar (1972a) reported that there is no difference between two types of supporting cells in their abundance or relation to the receptors but when supporting cells lie together, the

group consists of one type of cells. In accordance with Bertmar (1972a) the ciliated and nonciliated supporting cells are distributed in different zones in N. chitala and O. bimaculatus. In the former fish the supporting cells, present in nonreceptory region, are densely ciliated but those present with receptor cells are nonciliated. In O. bimaculatus the nonciliated supporting cells are present in the distal ends of all the lamellae but the ciliated ones are present in the proximal part of the lamellae on both the sides of raphe, demarcating supporting and sensory zones. The posterior lamellae are provided with major bulk of nonciliated cuboidal supporting cells which are intermingled with mucous secretory goblet cells. In N. chitala the goblet cells are found with the ciliated supporting cells. The author is in agreement with Rahmani and Khan (1980) and Sharma (1981) that the grouping of different types of supporting cells in a zone or in small groups may be for some functional significance. The ciliated supporting cells in O. bimaculatus and N. chitala discharge the supporting function of olfactory epithelium and their heavy ciliation effectively creates water current through olfactory chamber. Sharma (1981) reported similar functional significance of ciliated supporting cells in H. fossilis, C. carpio, M. armatus armatus and E. denricus. Singh and Singh (1986) also correlated the functional aspect of different cellular components of some hill stream fishes with their feeding habits.

In N. nandus the supporting cells are subjected to great displacement due to tremendous flow of basal cells to any peripheral direction of the olfactory mucosa. This leads the peripheral or distal surface of lamella to convert in peculiar form of elevations or deepenings. The former may be in the shape of cuneiform, filiform, fungiform, hillock and minor elevations whereas the latter in the shape of tubule, flask, funnel and vacuole like deepenings. The flow of basal cells makes the olfactory epithelium transitional which is supposed to give rise any of the form described above for the purpose of enhancing the olfactory area as well as to accommodate the flow of basal cells. The transitional stage of supporting cells is observed in C. carpio by Sharma (1981) where muciferous nature of olfactory epithelium followed by the flow of basal cells resulted specific formations on the lamellar surface. Ojha and Kapoor (1973) in L. rohita, Kapoor and Ojha (1974) in C. punctatus observed muciferous activity in the supporting cells.

The supporting cells in O. bacaila are generally uniform except in the conditions of lamellar swelling, narrowing terminal curving, knobbing and trifurcation. In such formations the supporting cells are transformed in accordance to respective shapes. Similar findings were observed by Sharma (1981) in H. fossils where curving, budding and detachment bear different types of supporting cells suited to a particular formation in a lamella.

According to Moulton and Beidler (1967) the supporting cells significantly discharge their secretory and nutritional function rather than providing mechanical support to the receptors. In N. chitala the supporting cells are richly supplied with intervening mucous secretory goblet cells. This may be due to the positive muciferous activity of some supporting cells which in due course of time convert into goblet cells and may be observed in different formative stages, ranging from mucous filled to empty theca of these cells. In Q. bimaculatus mega and micro type of goblet cells observed in the hinder and distal ends of the lamellae. The former converts from the supporting whereas the latter from basal cells, with the result of their muciferous activity in the respective zones of the olfactory epithelium. In N. nandus the supporting cells exhibit no muciferous activity. The presence of beaked goblet cells (in different formative phases) in the mucosa of Q. bacaila show muciferous nature of its supporting cells. This is in accordance with Kapeer and Ojha (1974) that apart from their supporting function, the supporting cells in the olfactory mucosa have been assigned the role of secretion and isolation of receptor cells. On the other hand Gerebtzoff and Shekapenko (1952) and Gerebtzoff (1953) contradicted the idea of secretory nature of supporting cells. Doroshenko and Motavkin (1987) also described the secretory nature of supporting cells and reported secretory cells in indifferent and sometimes even in sensory epithelium.

Le Gros Clark and Warwick (1946), Bloom (1954), Yamamoto et al. (1965), Frisch (1967), Seiffert (1968) observed secretory fluid or granules in the supporting cells of different animals. The muciferous activity of supporting cells has been reported by Ojha and Kapeer (1973), Kapeer and Ojha (1974), Rahmani and Khan (1980) and Sharma (1981). The author is of the opinion that the goblet cells have no separate origin but they are generated from the supporting cells and their degree of occurrence varies with the secretory nature of olfactory epithelium.

The supporting cells in O. bacaila are ciliated and distributed uniformly in all the lamellae except in some specific formations where they are nonciliated. The olfactory epithelium of N. chitala is clearly divisible into supporting and sensory zones. The former is supplied with columnar ciliated supporting cells whereas the latter with nonciliated cuboidal cells. The ciliated supporting cells bear clusters of cilia entangled with mucous while cuboidal ones isolate the receptors in the sensory zone. This is in agreement with Kapeer and Ojha (1974) who observed that the supporting cells isolate receptors. In O. bimaculatus the receptor cells are distributed among ciliated and nonciliated supporting cells but nonciliated supporting cells bear rich supply of sensory element. In O. bimaculatus the ciliation is dense and entangled with mucous secretion. The supporting cells in N. nandus are ciliated in uniform surface but in transi-

tionary one they are nonciliated and exhibit great variation under the pressure of migration of basal cells in different directions of the olfactory mucosa. The mucous secretory activity is not very much prevalent in N. nandus, however, few goblet cells at different levels of mucosa are rarely visible. Singh and Singh (1986) reported different forms of ciliated cells (type one and two), supporting cells, pigment cells, microvillus cells and rod cells in the fishes Barilius bendelises, Schizothorex richardsonii, Puntius chilinoides and Neomacheilus montannus. The author is of the opinion that ciliated supporting cells are always columnar in shape but in indifferent and sensory regions of the olfactory epithelium, they acquire nonciliated and cuboidal condition.

In the present study the author observed cilia in all the four fishes (N. nandus, O. bimaculatus, N. chitala and O. bacaila) belonging to different habit and habitat. Gooding (1963) in Katsuwonus pelamis and Gemne and Doving (1969) in Lota lota observed total absence of cilia in supporting cells. Bannister (1965) described cilia in supporting cells of Phoxinus phoxinus, Gasterosteus but also reported that free surface of cilia bear irregular microvilli. In N. chitala and O. bimaculatus the clusters of cilia are observed in the mucosa of olfactory epithelium, giving an impression that two or more cilia may be coming out from these supporting cells. In N. nandus and O. bacaila clustering of cilia is not

observed and single cilium is coming out from the outer limb of the supporting cell. It can be inferred at this juncture that the fishes which are totally dependent on ciliary mode of water circulation through the olfactory chamber are provided with clusters of cilia and exhibit more muciferous activity in the supporting zone. In O. bacaila the wide posterior nasal opening allows the constant exposure of olfactory surface to the water and in N. nandus well developed ethmoidal and lacrymal accessory nasal sacs operate the water circulation through the olfactory chamber. Because of this reason the olfactory epithelium of N. nandus and O. bacaila bears light ciliation as compared to those of O. bimaculatus and N. chitala

Holl (1965) suggested that nonciliated supporting cells isolate the receptors and contribute to the metabolism between olfactory epithelium and blood, whereas ciliated ones act for the distribution of mucous on the epithelial surface. Holl (1965) and Pipping (1926) were of the view that ciliary activity of olfactory epithelium creates water current through the olfactory chamber. DE Lorenzo (1960) was of the view that the supporting cells may be involved in the perception of the sense of olfaction in some way or other. But Kapoor and Ojha (1974) treated this view as an erroneous conception. The author is also of the view that marked and frequent existence of the receptor cells in the olfactory epithelium of fishes under study, leave no chance for

supporting cell to perform the function of olfactory reception. Therefore, the supporting cells are meant for the maintenance of integrity of the olfactory epithelium and to provide the mechanical support to the dendrite of the receptor cells, keeping them erected in the position for the reception of senses from the water current, passing through the olfactory chamber.

#### The receptor cells:

Rahmani and Khan (1980) reported that the receptor cells are almost uniformly scattered in young Anabas testudineus but in an adult they are grouped and burried in depressions in between the secondary lamellae. Singh (1972) observed similar pattern of distribution of receptor cells in Bagarius bagarius, Xenentodon cancila and Botia dario. The distribution of receptor cells in different patterns of olfactory epithelium is significantly variable. Iwai and Nakamura (1964), Malyukina et al. (1969), Yamamoto and Ueda (1977) observed great variability in the distribution of receptor cells with other cellular components. Doroshenko and Motavkin (1987) explored the variability in the distribution of cellular elements to the extent that the olfactory epithelium is distinct into receptory and indifferent epithelia. Singh and Singh (1986) distinguished ciliated cells (type one and two), microvillus cells, pigment granules and rod cells in the olfactory epithelium of four hill stream fishes.

In the present investigation the author noticed that the distribution of receptor cells is subjected to the great variation with respect to the general condition of olfactory epithelium. In N. nandus the receptor cells are irregularly distributed in all the places of olfactory epithelium but they are concentrated in specific deepening, created by the migration of basal cells. The concentration of receptors at one place is termed as olfactory bud which may be flask, funnel, tubule and vacuole like. The receptors are absent in the adjacent elevations in the shape of cuneiform, filiform, fungiform, minor, major and hillock elevations. In N. chitala the distribution of receptor cells becomes strictly restricted in the sensory zone, clearly separating it from the supporting one. In O. bimaculatus the receptor cells are distributed throughout the olfactory surface but they are more in number among the nonciliated supporting cells in the distal end of the lamellae and in the hinder ones. O. bacaila comprises of uniformly distributed receptors in its olfactory surface showing their well stained dendrites coming out to the interlamellar spaces.

Dogiel (1987), Morrill (1898), Jagadowski (1901) and Castello (1956) reported spindle, conical and columnar receptor cells in fishes and frogs. In Salmo, rod and spindle shaped receptor cells were described by Holl (1965). He further reported spindle shaped receptor cells in all the fishes studied by him whereas rod shaped receptor cells were

found in Salmo gairdneri, Salmo trutta fario, Esox lucinus, Pleuronectes platessa and Trigla corex. Singh and Singh (1986) reported different types of receptor cells, named as ciliated cell (type one and two), microvillus cell, and rod cell in some hill stream fishes. The olfactory epithelium of N. nandus represents primary neurones, rod and spindle shaped receptor cells. The rod shaped receptor cells in N. nandus are observed on the general surface of the olfactory epithelium where basal cells have not shown their migratory activity. The spindle shaped receptor cells are rare in occurrence and can accidentally be observed in the olfactory epithelium. The primary neurones are richly concentrated in the specific deepenings, taking a shape of olfactory bud. The primary neurones are accumulated in different forms of deepenings for the reception of olfactory sensation which can be named as olfactory bud. In such formations, the dendrites are concentrated, sending their short and elongated stereocilia into the interlamellar spaces for the reception of olfactory sensation through the circulating water current. The findings of N. nandus are in accordance with Sharma (1981) wherein C. carpio the formation of olfactory bud takes place in the spaces created by the empty theca of goblet cells. Bertmar (1972) reported these conditions in the olfactory epithelium of sea trout. Kolmer (1927) reported that rod and spindle shaped receptor cells are present in the mucosa of man. Neuhaus (1955) reported four receptor types in dog. Bannister

(1965) described variation in the morphology of receptor cells in Phoxinus phoxinus. Holl (1965) was of the opinion that two types of receptor cells (spindle and rod shaped) represent different ontogenetical stages. Bannister (1965), Moulton and Beidler (1967) described them as the variation of one type resulted due to the tight packing of the cells. The author is of the opinion that rod shaped receptor cells are always present in broad olfactory epithelium among the columnar supporting cells whereas primary neurones are always present in some form of interruptions in the olfactory epithelium, sending short dendrites solitorily or in groups. In latter case the olfactory bud is formed due to the accumulation of dendrites at one spot.

The formation of specific deepenings and elevations in the olfactory epithelium of N. nandus is a common feature. This may be due to the abundant distribution of basal cells and their subsequent migration in the olfactory epithelium, causing displacement of other cellular components, consequently, forming these different shapes. This is an adaptability of N. nandus for increasing the area of olfactory surface, simultaneously compensating the presence of less number of lamellae in its rosette. The olfactory bud may be observed at any level of olfactory epithelium, depending upon the degree of migration of basal cells and subsequent displacement of other cellular components.

The primary neurones, spindle and rod shaped receptors in the olfactory epithelium of N. nandus maintain their independent identity and no synaptic contact in between any two receptors is observed. This is in agreement with the findings of Ottoson (1963), Yamamoto et al. (1965), Moulton and Beidler (1967), Kleerekeper (1969), Graziadei and Metcalf (1971) and Rahmani and Khan (1980). They described that receptors maintain independent identity and no synaptic contact can be observed in the olfactory epithelium.

Contrary to the findings of above workers, Ojha and Kapoor (1973) in Labeo rohita and Kapoor and Ojha (1974) in Channa punctatus observed secondary neurones in the olfactory epithelium which establish synaptic contact with primary neurones. Similar picture of receptors is observed in N. chitala of present investigation. The demarcation of zonation is so acute that sensory zone is clearly distinct from the nonsensory (supporting and nutritional). This is in agreement with the findings of Doroshenko and Motavkin (1987) who reported distinct and indifferent epithelia in the olfactory folds (lamellae) of some teleosts. The sensory zone of N. chitala is provided with primary and secondary receptor cells which are isolated by nonciliated supporting cells. The establishment of synapse in between the dendrite of secondary neurone and axon of primary neurone is commonly observed in this specific zone. The axon of secondary neurone extends to folium olfactorium alongwith the basement membrane whereas the

dendrite of primary neurone extends to the interlamellar space for the reception of olfactory sensation. The secondary neurones are identical to the spindle shaped receptor cells in N. chitala and occasionally send filamentous dendrites to the interlamellar spaces.

The author is of the opinion that the presence of primary and secondary receptor cells alongwith the formation of synapses in between them may be the characteristic of some fishes in which L. rohita (Ojha and Kapoor, 1973), C. punctatus (Kapoor and Ojha, 1974) and N. chitala (in present study) can be listed.

The receptor cells in O. bimaculatus are represented by rod shaped, spindle shaped and primary neurones. The spindle shaped receptor cell in this fish corresponds to the secondary neurones of L. rohita (Ojha and Kapoor, 1973), C. punctatus (Kapoor and Ojha, 1974) and H. fossilis (Sharma, 1981) but they are situated at variable depth in the olfactory mucosa. The primary neurones are present at the angles in between the raphe and lamellae and also in the hinder lamellae and their terminal tips. The rod shaped receptor cells appear as giant cells in the proximal zone among ciliated supporting cells. This corresponds to the olfactory epithelium of some hill stream fishes (Singh and Singh, 1986). The presence of spindle shaped receptor cells is occasional and confined in the distal zone. They can be treated as short bodied cells,

formed by the basal cells and could not attain a length of rod shaped receptor cell. With regard to the size of these receptors, the nuclei may be rounded, oval and elongated and the length of axon and dendrite depend on their position in the olfactory mucosa.

In the olfactory epithelium of O. bacaila, the receptor cells are seen intermingled with the basal cells and their identity can be recognised by long filamentous axon and dendrites coming out from these cells. The spindle shaped receptor cells in O. bacaila can be observed in its olfactory mucosa. Vinnikov (1956) claimed that the cilia of receptor cells are the main element of perception and they act like the antenna for getting the sensation from the odorants, circulating through the water current. Similarly the olfactory cilia coming out from the tip of axon in O. bacaila are more prominent and giving an appearance of long motile perceptory structure like the antenna, projecting into the interlamellar spaces. The spindle shaped receptors are occasionally grouped in two or very few more numbers in the olfactory epithelium of O. bacaila. This is in agreement with the findings of Graziadei (1971) as he shown that the neurones in the olfactory epithelium may join together at specific points to make this more sensitive for perception. Similar kind of packing of receptor cells was described by Holl (1965) in a cat fish, Ictalurus and by Bloom (1954) in toads and frogs as pointed out by Bannister (1965) and Moulton and Beidler (1967).

This can be taken into consideration that O. bacaila and N. chitala possess two types of receptor cells (Primary neurones and spindle shaped receptor cells) whereas N. nandus and O. bimaculatus with primary neurones, spindle and rod shaped receptor cells. Polymorphic nature of the receptor cells is described by Dogel (1886), Jagadowski (1901), Kolmer (1927), Allison (1953), Branson (1963), Bannister (1965), Sharma (1981), Singh and Singh (1986) and Doroshenko and Motavkin (1987). The author is of the opinion that these forms of receptors are the derivative of basal cells and their shape is due to their packing in accordance with the concentration of other cellular components and their situation in the olfactory mucosa.

The distal tips of dendrites of the receptors in fish and cyclostomes swell up into olfactory vesicles which bear olfactory hairs (cilia) (Jagadowski, 1901; Vinnikov, 1956; Trujillo-Cenoz, 1961; Branshtein, 1963, 1965; Bannister, 1965; Kleerekoper, 1969; Ojha and Kapoor, 1973; Kapoor and Ojha, 1974; Rahmani and Khan, 1980; Sharma, 1981; Singh and Singh, 1986; Doroshenko and Motavkin, 1987). Similar formation of olfactory vesicle was also reported in other vertebrates by Van Der Stricht (1909), LE Gros Clark and Warwich (1946), Bloom (1954), De Lorenzo (1957), Ottosen (1963), Frisch (1967), Moulton and Beidler (1967), Whelan et al. (1986). The formation of olfactory vesicle is clearly observed in all the fishes of present investigation (N. nandus, O. bimaculatus,

N. chitala and O. bacaila). In N. chitala the olfactory vesicle can be seen in the sensory zone alternating to non-ciliated supporting cells. They are reverse V shaped in structure and bear microvilli which project into the interlamellar spaces. The dendrites of receptor cells in the olfactory epithelium of O. bacaila are in the form of olfactory (sensory) cilia which are found alternated by the cilia of supporting cells. These are coming out from the terminal tips of dendrites which at number of places take the form of olfactory vesicle. In N. nandus rod shaped receptor cells are microvillus implanted on their terminal ends but the long dendrite of spindle shaped receptor cells end terminally in the form of olfactory vesicle with elongated cilia. In the specific deepenings of the olfactory epithelium of N. nandus, neurones project collectively as such leaving their terminal tips exposed to the interlamellar spaces but do not bear any specific formation. This may be a condition because of the fact that such dendrites are situated deep in the olfactory mucosa and collectively form olfactory bud where localized effective reception of sensation takes place. The spindle shaped receptor cells in N. nandus send filamentous cilia to the interlamellar spaces and no well marked olfactory vesicle is observed. In the olfactory epithelium of O. bimaculatus the olfactory vesicle formation is not prominent but the rod shaped receptor cells bear elongated sensory cilia which may be of variable sizes. This

is in agreement with Doroshenko and Motavkin (1987) who observed flagella in the sensory epithelium of Limanda yokohamae. His description of sensory flagella may be an exceptionally elongated cilia as the case in O. bimaculatus (of present study).

Wilson and Westerman (1967) reported cilia and microvilli on the same receptor cells in Carassius auratus similar to the finding of Malyukina et al. (1969). The olfactory receptor cells of N. nandus, O. bimaculatus, N. chitala and O. bacaila exhibit various types of olfactory cilia which probably reflect the functional heterogeneity of the sensory cells.

Yamamoto and Ueda (1977) identified four types of receptor cells on the basis of the surface specialization (i) the first type bear 10-30 relatively long cilia on a wide and flat surface. All the cilia of this type inclined in the same direction over the wide range of the epithelium. This was called type one ciliated cell (later they added that the cilia of the type one ciliated cells may be motile and might be associated with the circulation of fluid between the lamellae), (ii) type two ciliated cell has 8-12 short cilia which project radially from the round apex of the cell, (iii) the third type has a tuft of hundred or more microvilli but no cilia thus called as microvillus cell, (iv) the fourth is rod cell which neither bears cilia nor microvilli and its apical end protrudes as simple rod from the epithelial surface. Bannister (1965) and Schulte (1972) have also described type

one ciliated cells but they regarded these cells to be non-sensory. Ichikawa and Ueda (1977) have found by the retrograde technique that type two ciliated cells and microvillus cells are genuine receptor cell, because when olfactory nerve is transected, only these two types of cells degenerate, while the type one ciliated cells and rod cells remain unaffected. This proves that type one ciliated cells are not receptor cells.

In the present study it is observed that type one ciliated cells correspond to the ciliated supporting cells of N. chitala. Here these supporting cells bear more than ten very elongated and stout cilia show their inclination towards one side and come out from their wide and flat distal limb. Type two ciliated cells correspond to the receptor cells of O. bacalla where cilia are comparatively short and less in number, projecting into the interlamellar spaces. The receptor cells of N. chitala and O. bimaculatus are microvillus type (3rd type of cell) but the protruding end of primary neurones in crypts or empty theca in N. nandus may be identified as fourth type of receptor cells as described by Yamamoto and Ueda (1977).

#### The mucous secretory goblet cells

Kubiak (1962) in Blicca byorkna, Bannister (1963) in Phoxinus phoxinus, Pfeiffer (1963) in Oncorhynchus, Bertmar (1972) in Salmo, Singh (1972) in Baqarius baqarius and Botia dario, Devitsyna (1972) in Gadus moruha, Eleqinus novaga and

Lota lota, Ojha and Kapoor (1973) in Labeo rohita, Kapoor and Ojha (1974) in Channa punctatus, Sharma (1981) in Cyprinus carpio, Heteropneustes fossilis, Mastacembalus armatus armatus and Esomus danricus, Doroshenko and Motavkin (1987) in Limanda yokohamae reported mucous secretory cells, as an important cellular component of the olfactory epithelium. The detailed review of Kleerekoper (1969), Hara (1975) also mentioned that the mucous secretory activity, in the olfactory epithelium of fishes, assists in the reception of olfactory sensation.

In the present investigation the mucous secretory activity is prominently noticed in O. bimaculatus, N. chitala and O. bacaila but in N. nandus such activity is very restricted and the presence of goblet cells is rarely noticed.

The olfactory epithelium of Xenentodon cancila (Singh, 1972), Hybopsis gelida and Hybopsis aestivalis (Branson, 1963), Colisa fasciatus (Rahmani and Khan, 1979), Anabas testudineus (Rahmani and Khan, 1980) is devoid of goblet cells and thus no muciferous activity is reported in these fishes. Holl (1965) described mucous cells in both indifferent and sensory epithelium of Salmo especially in those places where secondary foldings are present. Bertmar (1972) also reported mature goblet cells in Salmo which lie uniformly in surface zone of the indifferent epithelium but are scattered in sensory epithelium. Similar to the findings of Holl (1965) and Bertmar (1972) the goblet cells are richly distributed

in the olfactory epithelium of O. bacaila and O. bimaculatus. In these fishes goblet cells may originate either from basal cells or from supporting cells as a result of their muciferous activity. The goblet cells in these fishes exhibit migratory feature as they can be observed at variable depth in different formative stages in the olfactory mucosa of O. bacaila and O. bimaculatus. The goblet cells discharge their mucous into the interlamellar spaces after reaching to the peripheral surface of the lamella. The migratory activity of goblet cells in O. bacaila is prominent as the formative stages of these cells can be noticed in basal or deeper zone but the discharge of mucous is always into the interlamellar spaces. In the lamellaeless area of O. bimaculatus the muciferous activity is very common which is probably for entangling the foreign material circulated with water and permitting clear water to the interlamellar spaces. The mucous secretory activity in O. bacaila and O. bimaculatus is in accordance with the olfactory mucosa of L. rohita (Ojha and Kapoor, 1973), C. punctatus (Kapoor and Ojha, 1974), M. armatus armatus, H. fossilis, C. carpio and E. denricus (Sharma, 1981). In these fishes the goblet cells can be observed in the deeper zone of mucosa but they discharge their mucous into the interlamellar spaces.

The theca of goblet cells of O. bacaila is more pronounced and projected out by a beak like structure which help in releasing the mucous into the interlamellar spaces.

This is in accordance with the findings of Sharma (1981) in E. denricus and M. armatus armatus.

N. chitala reveals muciferous activity, restricted in the supporting zone where some supporting cells are ultimately converted into full grown mucous secretory goblet cells. These goblet cells are common in occurrence in the supporting zone, regularly intermingled with the supporting cells.

In higher vertebrates the olfactory epithelium is kept moist by the secretion of Bowman's gland (Allison, 1953). This gland is absent in the fishes, however, unicellular goblet cells compensate the function of Bowman's gland.

In air breathing vertebrates the supra epithelial mucous layer dissolves the odorant particles to be smelled and wash away the material that has already been detected in the first sample of air (Hildebrand, 1974). In fishes there is no need of dissolution of the material for odour perception as the odorant dissolved in external medium (water), constantly circulates through the olfactory chamber. The mucous secretion in fishes plays important role in holding up the foreign material either in interlamellar spaces or in some form of lamellaeless area, permitting clear water to the delicate olfactory surface and thus preventing injuries and infections to it. Zeiske et al. (1976) explained that mucous secretion from goblet cells smoothen the water flow in the olfactory chamber and acting as shock absorbant due to water pressure in the olfactory mucosa. The statement of Andres (1966), that

in fishes the free surface of receptor cell is directly rinsed by the flow of water, is not correct (Zeiske et al., 1976). The mucous secretion is overlapped on the olfactory surface and thus helps in smooth flow of water in the olfactory chamber. Rosen and Cornford (1971) stated that the slime (mucous) has a remarkable capacity to decrease the friction of water in the Pacific Barracunda, Sphyraena argentea, for example, the friction of water decreases by as much as 65.6 per cent.

Bloom and Fawcett (1978) quoted that in mammals the only unicellular glands are the mucous secretory goblet cells which are scattered among the columnar cells of the epithelium on many mucous membranes. They further pointed out that goblet cells secrete mucous and are made up of an expanded apical end, filled with pale droplet of mucin. The basal end is containing a compressed nucleus with small amount of deeply stained cytoplasm. The expanded cup shaped structure is known as 'theca' which remains associated with the basal zone by a thin base like 'stem'.

The structure of goblet cell in the olfactory epithelium of N. nandus, O. bimaculatus, N. chitala and O. bacaila is exactly identical as described by Bloom and Fawcett (1978) with reference to mammal. In O. bacaila, O. bimaculatus and N. chitala the theca is expanded cup shaped with clearly visible nuclear complex which is compressed below

its base in the form of a deeply stained knob. In N. nandus the goblet cells are rounded, giving inconspicuous visibility of theca and its other associated structures.

The goblet cells in O. bacaila and N. chitala are more prominent, taking the shape of a wine cup. In the former a beak like protuberance is projected in interlamellar spaces. In N. chitala the goblet cells are elongated and equal to the size of supporting cell.

Ojha and Kapoor (1973), Kapoor and Ojha (1974), Sharma (1981) and Doroshenko and Motavkin (1987) described goblet cells of varying shapes and sizes with variable degree of mucous secreting activity. In the lamellaeless area of O. bimaculatus the mucous secretory activity is very prominent and goblet cells of different shapes and sizes can be observed. In N. nandus the olfactory mucosa is scantily supplied with the goblet cells but they are richly present in the accessory nasal sacs. The lamellaeless area of N. chitala is also richly provided with goblet cells. The author is of the opinion that the rich supply of goblet cells, in the lamellaeless areas of N. chitala and O. bimaculatus and accessory nasal sacs in N. nandus are for smoothening the water supply and entangling the foreign material, permitting clear water to the sensory surface. This is in agreement with the findings of Rosen and Conford (1971).

The association of goblet cells with aquatic mode of life can be traced out because they are present in fishes (Whitaker, 1970), amphibians (Farquhar and Palade, 1965) and aquatic snakes (Bannerjee and Mittal, 1978). Their presence in aquatic form is to minimize the friction between the body and water, thus increase the mobility of the animal. The mucous secretion in olfactory chamber is for allowing the smooth flow of water and protects the sensory epithelium from the effect of water friction in fishes.

The author attempted to classify the goblet cells under present investigation as those of with larger theca and other with smaller theca. The former are always seen among the supporting cells and the latter with basal zone. This is due to the fact that goblet cells may be originating either from the supporting or from the basal cells. The muciferous activity can be reported in both supporting as well as basal cells (Bertmar, 1972; Ojha and Kapoor, 1973; Kapoor and Ojha, 1974; Sharma, 1981). Thus evidently the goblet cells originated from supporting cells may be having elongated body as compared to those originating from basal cells. The former can be named as megagoblet while the latter as microgoblet cells. The microgoblet cells reveal migratory tendency as they have to reach the peripheral or outer surface of olfactory mucosa for the discharge of their mucous.

In Q. bimaculatus and Q. bacaila both types of goblet cells are seen and muciferous activity can be observed in

supporting and basal cells. But in N. chitala only megagoblet cells are observed as these are produced with the result of muciferous activity of supporting cells.

Bloom and Fawcett (1978) quoted that the secretion of mucous proceeds more or less continuously and the life span of an individual cell is only two to four days in the intestinal mucosa. Although goblet cell normally passes through a long secretory cycle but they may be made to expel nearby all of their secretion at once. Similar to above finding it is observed that the goblet cells in O. bacaila, O. bimaculatus and N. chitala exhibit continuous mucous secretory activity. In the olfactory mucosa of all these fishes, the goblet cells can be seen in different formative stages where the theca may be filled with mucous or may be empty after the discharge of its contents. In latter condition these cells cease their existence, creating the space for the flow of other cellular components.

#### The basal cells:

The occurrence of basal cells, in the olfactory mucosa of fishes and other vertebrates, is in a well demarcated basal zone just above the basement membrane (Allison, 1953; Graziadei, 1965; Andres, 1966; Wilson and Westerman, 1967; Gemne and Doving, 1967; Singh, 1972; Bertmar, 1972; Ojha and Kapeer, 1973; Kapeer and Ojha, 1974; Hara, 1975;

Zeiske et al., 1976; Branstein, 1976; Yamamoto and Ueda, 1977; Rahmani and Khan, 1980). These cells are undifferentiated and give rise to supporting cells (Schaeffer, 1932; Cordier, 1964; Ojha and Kapoor, 1973) or receptor cells (Andres, 1966; Thornhill, 1970; Graziadei and Metcalf, 1971) or both types of cells (Bertmar, 1972; Hara, 1975; Sharma, 1981; Singh and Singh, 1986; and whelan et al., 1986).

In the present study of N. nandus, O. bimaculatus, N. chitala and O. bacaila, the basal cells occupy the lower region forming a well defined basal zone in the olfactory mucosa of lamellae, raphe, lamellaeless area and accessory nasal sacs. In N. chitala the basal cells are scanty supplied in the supporting zone but they are present in greater bulk in sensory zone. In the former zone of N. chitala the basal cells are present in an uniform single layer below the supporting cells but in sensory they are intermingled with the receptors and nonciliated supporting cells. The accumulation of basal cells in N. chitala is seen in the supporting zone which appear as their preparation of transformation in other cellular components to fulfil the requirement of growth or to enhance the olfactory surface. This is in agreement with the statement of Kolmer (1927), Schaeffer (1932) and Cordier (1964). According to these workers the basal cells are additional or younger form of supporting cells which may ultimately replace the latter in the olfactory epithelium. The scanty supply of basal cells in the supporting

zone gives an idea that they are regularly replacing the supporting cells as the latter are continuously transforming into goblet cells and ceasing their life after the discharge of the mucous. Shantha and Nakjima (1970) contended that the basal cells could not give rise the supporting cells. This was an erroneous idea as Sharma (1981), Singh and Singh (1986) were of definite contention that the basal cells are the mother cells and all the time replacing the old and worn out cellular components in the olfactory epithelium of fishes. In O. bacaila the basal cells are present in greater bulk in the olfactory epithelium and alternate the receptor elements. The lamellae of O. bacaila exhibit swelling, narrowing, terminal curving, knobbing and trifurcation. All these formations are the resultants of the formative activity of basal cells and their flow in a particular direction.

Thornhill (1970), Graziadei and Metcalf (1971) used tritiated thymidine followed by autoradiography and attempted to identify that the basal cells of the olfactory epithelium are differentiated into olfactory neurones which are continuously replaced during the life time of an individual. Similar to these findings the primary and secondary neurones in N. chitala are continuously replaced by the basal cells in its sensory zone.

The basal cells in N. nandus are abundantly present and show their frequent migration and accumulation to any

direction in the olfactory mucosa, leading to the creation of elevations and deepenings of different shapes and sizes.

In Q. bimaculatus they are distributed in the basal zone in all the lamellae but become more concentrated in distal and hinder lamellae where they show their tendency of converting into goblet cells and sensory elements. In well composed ciliated zone of the lamella they are present almost in a single row, giving an idea of their regular conversion into supporting cells. The basal cells are seen extruded out into the interlamellar spaces alongwith mucous discharge in all the fishes of present study.

The muciferous activity of basal cells is noticed in the olfactory mucosa of Q. bimaculatus and Q. bacaila but in N. chitala only supporting cells display this activity. The author is of the opinion that the basal cells may directly or indirectly convert into goblet cells. In former condition they give rise to microgoblet cells whereas in latter (through supporting cell) into megagoblet cells.

The basal cells are also observed in the accessory nasal sacs of N. nandus and lamellaeless areas of N. chitala and Q. bimaculatus. The accumulation of the basal cells, in varying bulk in the mucosa of accessory nasal sacs or lamellaeless areas of rosette, minor to major elevations, is observed in their surfaces. The raphe of N. chitala, Q. bimaculatus and Q. bacaila is greatly supplied with basal cells just above the basement membrane, forming the basal zone.

Rahmani and Khan (1980) and Sharma (1981) reported that frequent mitosis in basal cells is a continuous process of formation of other cell types. The basal cells are observed in the connective tissue of central core or submucosa of raphe and the lamellae in N. nandus, O. bimaculatus, N. chitala and O. bacaila continuously replacing and supplementing the cellular components of this zone. The submucosa of above fishes bear variable supply of basal cells, fibroblasts, lymphoids, and histiocytes which are impregnated among the connective tissue fibres.

#### The pigment cells:

The sensory epithelium of hearing, olfaction, taste and touch is peculiarly supplied with pigment cells. The function of pigment cells is not fully known but it seems that they might be enhancing the smelling and hearing powers in the animal in some way or other (Allison, 1953). It is significant that albino animals, in which the pigment cells are lacking are particularly liable to poisoning (Allison, 1953). Malyukina et al. (1969) thought that there is a relationship between the intensity of colours of olfactory epithelium and the sensitivity of the organ of smell, darker the epithelium, higher the sensitivity. Hildebrand (1974) also favoured the view that pigments may enhance olfaction in some unknown way. Sharma (1981) observed pigment cells in M. armatus armatus, H. fossilis, N. notopterus and C. carpio.

Singh and Singh (1986) observed pigment cells in Barilius bendelishes, Schizothorex richardsoni and Puntius chilinoides.

In the present study the pigment cells are observed in the submucosa or central core of N. chitala, and O. bacaila but rarely observed in N. nandus. The concentration of pigment cells in above species of present investigation is along the blood vessels and connective tissue. In N. chitala branched and prominent pigmentation is observed in the central core of the lamellae and raphe.

Devitsyna (1972) on the basis of the comparative study of three gadoid fishes concluded that pigmentation of olfactory plates is a characteristic feature of some species with a reduced olfactory function. Novaga eleginus bears pigment cells while the lamellae of Lota lota and Gadus morhua are devoid of these cells.

Conversely to the findings of Devitsyna (1972) and in agreement with Malyukina et al. (1969), Hildebrand (1974) and Sharma (1981) the fishes of present study (N. chitala and O. bacaila) having well developed olfactory organ, show more supply of pigment cells as compared to N. nandus (of present study), having poorly developed olfactory organ with scanty pigmentation. Therefore, it can be concluded that the presence of pigment cells is related with the increase of olfactory behaviour and not with the reduction of olfactory function.

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**SUMMARY**

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## SUMMARY

The histomorphological study of the olfactory organs of four freshwater fishes (N. nandus, O. bimaculatus, N. chitala and O. bacaila) has been described in present investigation. The olfactory chamber of all these fishes lies on the dorsolateral surface of the head. It is situated close to eye orbit in N. nandus, close to snout in O. bimaculatus, inbetween the snout and eye orbit in O. bacaila and extending from snout to eye orbit in N. chitala.

Each olfactory chamber, in all the fishes under present study, opens outside by incurrent anterior and excurrent posterior nasal openings. They lie very close to each other in O. bacaila whereas in N. nandus at a little distance but at a considerable distance in O. bimaculatus and N. chitala.

The anterior nasal opening in N. nandus and N. chitala is rimmed. In the former it is nontubular whereas the latter is with forwardly directed and ventrally grooved anterior nasal tentacle. In O. bimaculatus it is provided with forwardly directed anterior nasal tube, giving an appearance of the terminal end of the tusk. In O. bacaila, the anterior nasal opening is placed on a short tube whose posterior margin is comparatively more elevated which act as

a nasal flap. The nasal flap, tentacle and tube help in deflecting the water to the anterior nasal opening.

The posterior nasal opening, in all the four fishes, is flushed with the general surface of the head. It is non-valvular in N. chitala and O. bacaila. In former it is oval and in confluence with the posterior elevated margins of the rosette but in latter it is wide and semilunar, permitting a major portion of the rosette in constant touch with water. The posterior nasal opening in N. nandus is valvular under which separate openings of ethmoidal and lacrymal accessory nasal sacs are present. In O. bimaculatus, the posterior nasal opening is situated on an irregular area of integument and remains covered by a valvular flap.

The olfactory rosette shows a great variation in shape, size and number of lamellae in all the four fishes. On the basis of categorization proposed by Bateson (1889), Burne (1909) and Teichmann (1954), the roughly leaf and boat shaped rosettes of O. bimaculatus and N. chitala can be placed under Bateson's (1889) rosette type 2; Burne's (1909) rosette column II and Teichmann's (1954) group III. Rounded rosette of O. bacaila can be placed under Bateson's (1889) rosette type 3, Burne's (1909) rosette column III and Teichmann's (1954) group II. The rosette of N. nandus is quadrangular and very much regressed with most of its part lamellaeless and peculiarly substituted with well developed

accessory nasal sacs. Such a rosette cannot be fit in any of the categories of Bateson (1889), Burne (1909) and Teichmann (1954). The placement of rosette of N. chitala in above categorization is not very much justified as it has acquired a considerable height with the erection of nasal and adnasal bones on both the lateral sides of the rosette.

The rosette, in the fishes of present study except N. nandus, is provided with anteroposteriorly elongated raphe, dividing it into two equal halves and the lamellae are attached on its either sides. In N. nandus the lamellae are parallel to the long axis of the body.

The number of lamellae varies from 7-10 in N. nandus, 64-104 in O. bimaculatus, 76-152 in N. chitala and 22-32 in O. bacaila. In all these fishes, the lamellae show a trend of successive increase in their number with the growth of fish. The dorsal surface of the lamellae of O. bimaculatus and N. chitala bear linguiform processes but in N. nandus and O. bacaila they are absent.

As regards the relationship of the brain with the rosette it is found that the olfactory bulb is sessile in N. nandus but pedunculate in O. bimaculatus, N. chitala and O. bacaila.

The ecological coefficient is calculated by the areas of two retinae, two rosettes and the length of telencephalon and mesencephalon. It is seen that N. nandus is a microsmatic fish where optic faculty is tremendously developed but O. bacaila is a eye nose fish, having both the faculties well developed. N. chitala and O. bimaculatus show the macrosmatic characteristic due to greater development of olfactory faculty. However, the amountable development of optic faculty in the former fish cannot be ignored, hence it plays supplementary role, making the fish more efficient. An attempt has also been made to correlate the eye nose, microsmatic and macrosmatic characteristics of these fishes with their general habits.

The flow of water, through the olfactory chamber, is unidirectional, created by anteroposterior beating of cilia in all the four fishes of present consideration. In N. nandus, the circulation of water through the olfactory chamber is assisted by the compression and expansion of accessory nasal sacs, operating with the protrusion of jaws and opening of mouth during its normal activity. The lamellaeless area, in O. bimaculatus and N. chitala, helps in maintaining the continuity of water in the olfactory chamber. In latter fish, the lamellaeless area in confluence with the posterior nasal opening creates suction of water synchronously with the opercular movement and yawning of the fish, inviting forceful entry of water through the anterior nasal opening.

The olfactory passage is longest in O. bimaculatus and N. chitala whereas in O. bacaila it is shortest. In N. nandus it is of moderate size. The vestibule, gallery and corridors are well defined in O. bimaculatus and N. chitala. The corridors are the interlamellar spaces which interconnect the vestibule with gallery. There is no such distinction of the olfactory passages in N. nandus and O. bacaila as former is provided with accessory nasal sacs and latter with wide semilunar posterior nasal opening, keeping most of the part of olfactory rosette exposed to external medium.

Histological observations exhibit that each lamella, in all the four species (N. nandus, O. bimaculatus, N. chitala and O. bacaila), is composed of a central core or submucosa, lined on either sides by cellular layer of mucosa. The basement membrane stands as partition inbetween mucosa and submucosa. The mucosa is mainly constituted of varied forms of supporting, receptor, mucous secretory goblet and basal cells. The submucosa, in all the four fishes, is greatly variable and variations are noted in the submucosa of lamellae of the same rosette with respect to broadening and amount of supply of fibroblasts, histiocytes, connective tissue fibres, vascular elements and pigmentation.

The ethmoidal and lacrymal accessory nasal sacs (in N. nandus), lamellaeless area (in O. bimaculatus) and floor of olfactory chamber (in O. bacaila) are also constituted of

submucosa and mucosa with excessive muciferous activity which may be a device for clearing the water by entangling foreign materials, circulating within it as well as minimizing the frictional damage, suspected by the continuous passing of water through the olfactory epithelium.

The variations, in the cellular composition of the lamellae, not only occur in different fishes of present study but also in the lamellae of the same rosette of an individual fish.

From the point of view of histological variations, the lamellae of N. nandus can be distinguished as initial, middle and hinder ones. The initial lamellae possess well built submucosa and mucosa. The former is broader, not at the expense of the latter in the middle but it is enormously developed in hinder ones, causing reduction in the thickening of mucosal zone.

The olfactory epithelium is provided with different types of deepenings and elevations. The former are in the shape of flask, funnel, vacuole and tube whereas the latter cuneiform, filiform, fungiform, minor and hillock elevations. The deepenings are the forms of crypts which are richly supplied with primary neurones, taking the shape of "olfactory bud" where olfactory cilia in all the receptors come out from the terminal ends of the dendrites, perceiving

olfactory sensation from the circulating water current. In addition to deepenings and elevations in the olfactory epithelium of N. nandus, minor lamellae, the offshoots of mucosal elements, are also observed in the interlamellar spaces of the rosette. The deepenings, elevations and minor lamellae are meant for increasing the olfactory surface in N. nandus.

The basal cells exhibit remarkable tendency of migration in different patterns, causing such deepenings and elevations. The olfactory epithelium is said to be transitional where basal cells are in the process of migration. The supporting cells in N. nandus are ciliated and columnar in well composed epithelium of a lamella and they become inconspicuously ciliated in the transitional epithelium.

The lamellae of O. bimaculatus are divisible into anterior and posterior ones. The former lamellae are having compact cellular organization and possess almost uniform body whereas the latter with broader submucosa and scattered cellular components of mucosa. Each lamella is distinguished into proximal and distal zones on the basis of the distribution of cellular elements. The ciliated supporting cells are present in the proximal whereas nonciliated in the distal zones of the lamellae of O. bimaculatus.

The distribution of cellular components is in a peculiar fashion in a lamella of N. chitala, showing clear cut zonation of sensory and supporting zones. The former extends from raphe to the middle of the rosette whereas latter from middle to the lateral wall of the olfactory chamber. In between these two zones, a notch like structure is visible. The submucosa, at this junction, is provided with the accumulation of connective tissue fibre bundles which form turgor whose branches extend in the supporting zone for strengthening the enlarged lamella. In the supporting zone the supporting cells are densely ciliated forming clusters which act as effective instrument for creating the water current through the olfactory chamber.

The lamellae of O. bacaila can be divided into initial, middle and hinder ones. The shape of lamellae in a rosette is greatly varied showing swelling, narrowing, terminal curving, clubbing, knobbing and trifurcation. In all such variations, the extrusion of cells can easily be seen in the interlamellar spaces. The cellular activity is responsible for the lamellar shapes, described above. Sometimes the terminal tips are detached from the mother lamella in the form of bud wherein all the cellular components are pooled.

The ciliated supporting cells in O. bacaila are densely distributed in the proximal and middle regions of

initial and middle lamellae but rarely in hinder ones and floor of olfactory chamber. The nonciliated supporting cells are commonly observed in hinder lamellae, floor of olfactory chamber, knobs and curvings. They are also present intermingled among the ciliated supporting cells.

The olfactory epithelium of N. nandus and O. bimaculatus is provided with primary neurones, spindle and rod shaped receptor cells. N. chitala bears primary and secondary receptors whereas O. bacaila with primary neurones and spindle shaped receptor cells. The secondary receptors of N. chitala and spindle shaped receptor cells of O. bacaila are identical cellular elements but named differently as the latter remain independent and former establish synaptic contact with primary receptors.

In N. nandus, the primary neurones are abundantly present in the deepenings of different shapes (olfactory crypts), forming olfactory sensory unit, "the olfactory bud". The rod and spindle shaped receptor cells are distributed in the mucosa in solitary manner among the supporting cells.

In O. bimaculatus the primary neurones are present in groups in the distal ends and angles of lamellae, attached with raphe. In the distal ends of posterior lamellae of O. bimaculatus, the dendrites of spindle shaped receptor cells occasionally make synaptic contacts with the axons of

primary neurones. The rod shaped receptor cells are distributed in the proximal whereas spindle shaped in proximal and distal zones of lamellae.

In N. chitala, it is remarkably noticed that the sensory zone is provided with primary and secondary receptors. The dendrites of latter and axons of former usually make synapses. It is occasionally observed that the secondary receptor remains as an independent element and its dendrite is projected in the interlamellar space in the form of olfactory vesicle or cilia. The receptors in N. chitala are very prominent and present in regular succession alternated by nonciliated supporting cells. The synaptic contact, between two receptors, is a common feature of sensory zone of N. chitala but in O. bimaculatus it is rare in occurrence in the distal zone of posterior lamellae.

The olfactory epithelium of O. bacaila is abundantly supplied with receptor cells. The primary neurones are richly distributed in the tips of lamellae. They may also be seen intermingled with the supporting and spindle shaped receptor cells. The spindle shaped receptor cells are uniformly and commonly observed in all the regions of olfactory epithelium of O. bacaila.

The olfactory epithelium of the lamellae and associated structures are characterized with the presence

of mucous secretory goblet cells. In N. nandus the goblet cells are rare in the lamellar epithelium but in ethmoidal and lacrymal accessory nasal sacs, they are abundantly present. In O. bimaculatus the goblet cells are commonly distributed in the distal zone of lamellae and lamellaeless area but rarely in the proximal zone. In N. chitala they are restricted in supporting zone with elongated theca, filled with mucous secretory contents. In O. bacaila the mucous secretory goblet cells are micro and mega types which may be originated from basal and supporting cells respectively. In the floor of olfactory chamber, the muciferous activity is maximum in O. bacaila. Beaked goblet cells are also seen in O. bacaila which may be a device for easy discharge of mucous in the interlamellar spaces.

The mucous secretory goblet cells are unicellular glands which in N. nandus are provided with round to elongated, in O. bimaculatus with elongated and short, in N. chitala with wine cup shaped elongated and in O. bacaila with both types (short rounded and elongated) of theca. The nuclear contents, in the goblet cell of all the fishes under study, are compressed in to a triangular area which remains connected with a stalk to underlying cellular region. The theca, in all these fishes, may be filled with mucous secretory contents, empty or in intermediate condition. The goblet cells discharge their mucous in the interlamellar

spaces where it entangles foreign materials and allows clear water to circulate through the delicate surface of the olfactory epithelium.

In N. nandus and O. bacaila, the activity of basal cells is very prominent. Their migration is responsible for different shapes of lamellae and microformations but in extreme condition they become overflow, consequently, extruded out in the interlamellar spaces from these formations. The basal cells in N. chitala and O. bimaculatus are not very much activated and uniformity of lamellar surface is maintained except the broadening and narrowing of submucosa. The grouping of basal cells can be seen in all the four fishes which may be a preparation in the direction of replacement, repair and formation of some other cellular components, required for the regular functioning of the olfactory epithelium.

The pigment cells are observed in the submucosa of N. chitala, O. bacaila and N. nandus which are found submerged in the connective tissue fibres and surrounding to the blood capillaries and sinuses. The pigment cells in N. chitala are remarkably branched and restricted in the supporting zone. N. nandus shows rare occurrence of pigment cells whereas they are absent in O. bimaculatus.

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**BIBLIOGRAPHY**

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## BIBLIOGRAPHY

- Allison, A.C. (1953). The morphology of the olfactory system in vertebrates. Biol. Rev. Cambridge Phil. Soc. 28: 195-244.
- Andres, K.A. (1966). Der Feinbau der Regio olfactoria Von Makrosmatikern. Z. Zellforsch. 69: 140-154.
- Atz, J.W. (1952). Narial breathing in fishes and the evolution of internal nares. J. Rev. Biol. 27: 366-377.
- Banerjee, T.K. and Mittal, A.K. (1978). Epidermal mucous cells in the chequered water snake, Natrix piscator (Colubridae: Squamata): A cytochemical investigation. Zool. Jour. Linn. Soc. 63: 289-293.
- Bannister, L.H. (1965). The fine structure of the olfactory surface of teleostean fishes. Quart. J. Microscop. Sci. 106: 333-342.
- Bashor, D.P., Beuerman, R.W. and Easton, D.M. (1974). Ciliary action and normal movement of odorant wave fronts in gar fish nasal capsule of Lepidosteus osseus. Experientia, 30: 777-779.
- Bateson, W. (1889). The sense organs and perceptions of fishes with remarks on the supply of bait. D. Mar. Biol. Ass. 1: 225-256.
- Bertelsen, E. (1951). The ceratoid fishes ontogeny, taxonomy, distribution and biology. Dana Rep. No. 39: 1-276.
- Bertmar, G. (1965). The olfactory organ and upper lip in Dipnoi, an embryological study. Acta Zool. (Stockh.) 46: 1-40.
- Bertmar, G. (1972a). Scanning electron microscopy of olfactory rosette in sea trout. Z. Zellforsch. Mikroskop. Anat. 128: 336-346.
- Bertmar, G. (1972b). Secondary folding of olfactory organ in young and adult sea trout. Acta. Zool. 53: 113-120.
- Bertmar, G. (1972c). Ecostructural studies on olfactory organ in young and adult sea trout. Z. Morphol. Oekol. Tiere 72: 307-330.

- Bertmar, G. (1973). Ultrastructure of the olfactory mucosa in the homing Baltic sea trout Salmo trutta trutta. Marine Biol. 19: 74-88.
- Bhargava, H.N. (1959). Studies on the nasal organ and infranasal chamber in the family Mastacembelidae. Proc. First All-India Cong. Zool. Part 2, 169-177.
- Blaue (1884). Arch. f. Anat. P. 241 (Quoted by Burne, 1909).
- Bloom, G. (1954). Studies on the olfactory epithelium of the frog and the toad with the aid of light and electron microscopy. Z. Zellforsch. 41: 89-100.
- Bloom William, M.D, and Fawcett Don W, M.D. (1978). A text book of Histology. Tenth Ed., Asian Ed., W.D. Saunders Company, IGAKU SHOIN LTD., Tokyo, 990 pp.
- \* Bodrova, N.V. (1962). Retseptory khimicheskogo chuvstva lishcha (Receptors of chemical sensation of bream). Vopr. Ikhtiol. 2,4 (25) (R.Z. Biol., 1963, 1219).
- Branson, B.A. (1963). The olfactory apparatus of Hybopsis gelida (Girard) and Hybopsis aestivalis (Girard) (Pisces: Cyprinidae). J. Morphol. 113: 215-229.
- Bronshtein, A.A. (1963). Intravital observations of movement of the hairs of the olfactory cells. Dokl. Akad. Nauk. SSSR. Biol. Sci., Sect. 156: 371-374.
- Bronshtein, A.A. (1965). Histochemistry of the olfactory organ. Arkh. Anat. Gistol. Embriol. 48: 106-116.
- Bronshtein, A.A. (1976). Some peculiarities of fine structure of the olfactory organ in Elasmobranchs. Zh. Evolut. Biochem. Physiol. 12: 63-67.
- Bronshtein, A.A. and Ivanov, V.P. (1965). Electron microscopic investigation of the olfactorial organ in the lamprey. J. Evol. Biochem. Physiol. 1: 251-261.
- Burne, R.H. (1909). The anatomy of the olfactory organ of teleostean fishes. Proc. Zool. Soc. (London), No. 2: 610-663.
- \*Castello, R. (1956). Effecti della neutrossicita da streptomicina e dudiostreptomicina Sulla funzione olfattiva. Minerva Otorinolaring. 6: 129-135.
- Copeland, M. (1912). The olfactory reactions of the puffer or swell-fish Spheroides maculatus (Bloch and Schneider). J. Exp. Zool. 12: 363-368.

- Cordier, R. (1964). Sensory cells. In The Cell, Volume IV, Brachet and Mirsky Editors, Academic Press, New York.
- Davis, B.J. and Miller, R.J. (1967). Brain patterns in Minnows of the genus Hybopsis in relation to feeding habits and habitats. Copeia 1967 (No.1): 1-39.
- De Lorenzo, A.J.D. (1957). Electron microscopic observations of the olfactory mucosa and olfactory nerve. J. Biophys. Biochem. Cytol. 3: 839-848.
- De Lorenzo, A.J.D. (1960). Electron microscopy of the olfactory and gustatory pathways. Ann. Otol. Rhinol. Laryngol. 59: 410-420.
- \* Derivot, J.H. and Godet, M.D.R. (1979). Anatomie fonctionnelle de l'organe olfactif de Protopterus annectens Owen (Dipneustes): Contribution a' la connaissance du mecanisme d'irrigation de l'organe olfactif., Acta. Zool. (Stockh.), 60: 251-257.
- Davitsyna, G.V. (1972). Morphology of the organs of olfaction in the Gadidae. J. Ichthyol. 12: 994-1002.
- \* Dogel, A.S. (1886). Stroenie obonyatel'nogo organa u ganoid kostnykh rybi amfibii (Structure of the olfactory organ in the ganoids of bony fishes and amphibians). Tr. Obshch. Estestvozn. Pri. Kazansk. Univ., 16
- \* Dogiel, A. (1887). Uber den Bau des Geruchsorganes bei Ganoiden, knochenfischen und Amphibien. Arch. Mikr. Anat. 29: 74-139.
- Doroshenko, M.A. and Metavkin, P.A. (1987). Surface structure of the olfactory organ in marine teleost fishes. Arkh. Nat. Gistol. Embriol. 91(10): 38-47.
- Doving, K.B. and Thommesen, G. (1977). Some properties of fish olfactory system. In Olfaction and Taste VI, Paris 1977; 175-183.
- Doving, K.B., Dubois-Dauphin, M., Holley, A. and Jourdan, F. (1977). Functional anatomy of the olfactory organ of fish and ciliary mechanism of water transport. Acta. Zool. (Stockh), 58: 245-255.
- Eaton, T.H.Jr. (1956). Notes on the olfactory organs in Centrachidae. Copeia No. 3: 196-199.
- Evans, H.M. (1935). The brain of Gadus with special reference to the medula oblongata and its variation according to the feeding habits of different Gadidae I. Proc. Roy. Soc. London, 117: 367-399.

- Evans, H.E. (1952). The correlation of brain pattern and feeding in four cyprinid fishes. J. Comp. Neurol. 97: 133-142.
- Farquhar, M.G. and Palade, G.E. (1965). Cell junctions in amphibians skin. J. Cell. Biol. 26: 263-291.
- \*Frisch, K. Von. (1941). Über einen Schreckstoff der Fischehaut und Seine biologische Bedeutung. Z. Vergl. Physiol. 29
- Frisch, D. (1967). Ultrastructure of mouse olfactory mucosa. Am. J. Anat. 121: 87-120.
- Gemne, G. and Doving, K.B. (1969). Ultrastructural properties of primary olfactory neurones in fish (Lota lota L.). Am. J. Anat. 126: 457-476.
- \*Gerebtzoff, M.A. et Shekapenko, G. (1952). Researches Sur le pigment de la muqueuse olfactive. C.R. Ass. Anat. 38 Reunion Nancy 1951, Fasc. 68: 511-516.
- \*Gerebtzoff, M.A. (1953). L' olfaction Structure de l'organe olfactif et mecanisme de l' olfaction. J. Physiol., Paris, 45: 247-283.
- Gooding, R.M. (1963). The olfactory organ of the Skipjack Katsuwonus pelamis. F.A.O. Fish Rep. 3: 1621-1631.
- Graziadei, P. (1965). Electron microscopic observations on the olfactory mucosa of the cat. Experientia, 21: 274-275.
- Graziadei, P.P.C. (1971). The olfactory mucosa of Vertebrates. In: Hand book of Sensory Physiology. (L.M. Beidler, ED.), Vol. IV(1), pp. 29-58. Berlin - Heidelberg - New York. Springer.
- Graziadei, P.P.C. and Metcalf, J.F. (1971). Autoradiographic and ultrastructural observations on the frog's olfactory mucosa. Z. Zellforsch. 116: 305-318.
- Gregory, W.K. (1951). Evolution Emerging. Mac Millan Company, New York. (2 Vols)
- \*Grimm, O. (1873). Ob okonchanii nervnykh Volokon v obonyatel' nom organe osetrovykh ryb (The terminals of nerve fibres in the olfactory organ of Sturgeon). Iz. St. Peterb. Obshch. Estestvoisp. 4(1)

- Gupta, O.P. and Shrivastava, R.K. (1973). An interesting type of olfactory organ in Indian Gar-fish of the family Belontiidae (Xenentodon cancila (Ham.)). Zool. Jb. Anat. Bd. 905: 450-453.
- Hagelin, L.O. and Johnels, A.G. (1955). On the structure and function of the accessory olfactory organ in lampreys. Acta. Zool. (Stockh.) 36: 113-125.
- Hara, T.J. (1975). Olfaction in fish. Prog. Neurobiol. 5: 271-335.
- Hara, T.J., Law, Y.M.C. and Hobden, B.R. (1973). Comparison of the olfactory response to amino acids in rainbow trout, brook trout and white fish. Comp. Biochem. Physiol. 45A: 969-977.
- Herald, E.S. (1961). Living fishes of the world. Hamish Hamilton, London.
- Herrick, C.J. (1908). On the phylogenetic differentiation of the organs of smell and taste. J. Comp. Neurol. 18: 157-166.
- Hildebrand, M. (1974). Analysis of vertebrate structure. John Willey and Sons, New York.
- \*Holl, A. (1965). Vergleichende morphologische und histologische Untersuchungen am Geruchsorgan der Knochenfische. Z. Morphol. Oekol. Tiere. 54: 707-782.
- \*Holl, A. (1973). Funktion morphologie der nase von Chimaera monstrosa (Holocephali). Z. Morphol. Oekol. Tiere. 74: 271-296.
- Hollister, G. (1932). Clearing and Dyeing Fish for bone study. Zoologica 12.
- Hopkins, A.E. (1926). Olfactory receptors in vertebrates. J. Comp. Neurol. 41: 253-289.
- Ichikawa, M. and Ueda, K. (1977). Fine structure of the olfactory epithelium in gold fish, Carassius auratus: Study of retrograde degeneration. Cell. Tissue Res. 183: 445-455.
- Iwai, T. and Nakamura, I. (1964). Olfactory organs of Tunas, with special reference to their systematic significance. Bulletin of Misaki Marine Biological Institute, Kyoto University, 7: 1-8.

- \* Jagodowski, K.P. (1901). Zur Frage nach der Endigung des Geruchsnerven bei den knochenfischen. Anat. Anz. 19: 257-267.
- Johnson, H.E. and Brown, C.J.D. (1962). Olfactory apparatus in the black rockfish, Sebastodes melanops. Copeia, 1962: 838-840
- Johnson, J.B. (1911). The telencephalon of gonoids and teleosts. J. Comp. Neur. 21: 489-591.
- Kapoor, A.S. and Ojha, P.P. (1972a). Functional anatomy of the olfactory organ in the moray, Muraena undulata. Japan J. Ichthyol. 19: 82-88.
- Kapoor, A.S. and Ojha, P.P. (1972b). Studies on the ventilation of the olfactory chambers of fishes with a critical revaluation of the role of accessory nasal sacs. Arch. Biol. Liege. 83: 167-178.
- Kapoor, A.S. and Ojha, P.P. (1972c). Occurrence of synapsis in olfactory epithelium of fish. Experientia 28: 64-65.
- Kapoor, A.S. and Ojha, P.P. (1973a). Functional anatomy of the nose and accessory nasal sacs in the teleost, Channa punctatus. Bloch. Acta. Anat. 84: 96-105.
- Kapoor, A.S. and Ojha, P.P. (1973b). The olfactory apparatus in the flatfish, Cynoglossus oligolepis Trans. Am. Micros. Soc. 92(2): 298-304.
- Kapoor, A.S. and Ojha, P.P. (1974). Histology of the olfactory epithelium of the fish, Channa punctatus Bloch. Acta. Anat. 87: 534-554.
- Kashiwayanagi, Makoto, Kimie Sai and Kenzo Kurihara (1987). Cell suspensions from porcine olfactory mucosa: Changes in membrane potential and membrane fluidity in response to various ororants. J. Gen. Physiol. 89(3): 443-458.
- Kleerekoper, H. (1969). Olfaction in fishes. Indian University Press, Bloomington.
- Kleerekoper, H. and Erkel, G.A. Van (1960). The olfactory apparatus of Petromyzon marinus. Canad. J. Zool. 38: 209-223.
- \* Kolmer, W. (1927). Gerichtsorgan. In: W. Von Mollendorf, Handbuch der mikroskopischen anatomie des Menschen, Ed. 3(1): S 192-249, Berlin.

- Kubiak, H. (1962). The blood vessels of the olfactory organ in the silver beam, Blicca biorkua. Acta. Biol. Cracoviensia Ser. Zool. 5: 57-66.
- Kyle, H.M. (1899). On the presence of nasal secretory sacs and a nasopharyngeal communication in teleosts, with special reference to Cynoglossus semilaevis Gthr. J. Linn. Soc. Zool. 27: 541-556.
- Lagler, K.F., Bardach, J.E. and Miller, R.R. (1962). Ichthyology. John Wiley and Sons Inc., New York, London, 445 pp.
- \*Laibach, E. (1937). Das Geruchsorgan des Alas (Anquilla vulgaris) in Seiner Verschiedenen Entwicklungstadien. Zool. Jahrb., Abst. Anat. 63: 37-72.
- Le Gros Clark, W.E. (1957). Inquires into the anatomical basis of olfactory discrimination. Proc. Roy. Soc. B 146: 299-319.
- Le Gros Clark, W.E. and Warwick, R.T.T. (1946). Pattern of olfactory innervation. J. Neurol. Neurosurg. Psychiatr. 9: 101-111.
- \*Liermann, K. (1933). Über den Bau des Geruchsorgans der Teleostier. Z. Anat. Entwicklungsgeschichte. 100: 1-39.
- Lowe, G.A., MacLeod (1975). The ultrastructural organization of olfactory epithelium of two species of gadoid fish. J. Fish. Biol. 7: 529-532.
- Malyukina, G.A., Dmitrieva, N.G., Marusev, E.A. and Yurkevich, G.V. (1969). Smell and its role in the behaviour of fish. Zoologiya, 1969: 32-78.
- Marshall, N.B. (1967). The olfactory organs of bathypelagic fishes. Symp. Zool. Soc. London No. 19: 57-70.
- \*Matthes, E. (1934). Geruchsorgan. In: Handbuch der vergleichenden Anatomie der Wirbeltiere. Vol. 2, pp. 897-948, Ed. L. Bolk, E. Groppert, E. Kallius and W. Lubesch. Urban and Schwarzenberg: Berlin.
- Miller, R.J. (1940). The telencephalic zonal system of the teleost, Corydora paliiatus. J. Comp. Neurol. 72: 149-176.
- Miller, R.J. and Evans, H.E. (1965). External morphology of the brain and lips in catostomoid fishes. Copeia 1965(4): 467-487.

- Morgan, G.C. Jr. (1975). The telencephalon of the sea cat fish, Galeichthys felis. J. Hirnforsch. 16:131-140.
- \* Morril, A.D. (1898). Innervation of the olfactory epithelium. J. Comp. Neurol. 8: 180-182.
- Moulton, D.G. and Beidler, L.M. (1967). Structure and function in the peripheral olfactory system. Physiol. Rev. 47: 1-52.
- \* Nagel, W. (1894). Vergleichend physiologische und anatomische Untersuchungen über den Geruchs und Geschmacksinn und ihre organe mit eiteitenden Betrachtungen aus der allgemeinen den Sinnesphysiologie Biol. Zool., 7: 18.
- \* Neuhaus, W. (1955). Die Form der Riechzellen des Hundes. Naturwissenschaften. 42: 374-375.
- Norman, J.R. (1963). History of fishes. Fourth edition, Ernest Benn Ltd., London, 398 pp.
- Ojha, P.P. and Kapoor, A.S. (1971a). Structure of the nose in some Indian teleostean fishes. Curr. Sci. 40: 550-551.
- Ojha, P.P. and Kapoor, A.S. (1971b). The functional anatomy of the olfactory organs in Garra gotyla, an Indian hill stream carp. Proc. Nat. Acad. Sci. India, 41(8); IV: 439-445.
- Ojha, P.P. and Kapoor, A.S. (1972). Functional anatomy of nose in the teleost, Wallago attu Bl. and Schin. Arch. Biol. Liege. 83: 105-116.
- Ojha, P.P. and Kapoor, A.S. (1973). Histology of the olfactory epithelium of the fish Labeo rohita Ham. Buch. Arch. Biol (Bruxelles) 44: 425-441.
- Ojha, P.P. and Kapoor, A.S. (1973a). Structure and function of the olfactory apparatus in the fresh water carp, Labeo rohita. Ham. Buch. J. Morphol. 140(1): 77-86.
- Ojha, P.P. and Kapoor, A.S. (1973b). The anatomy of the olfactory organs in the hill stream fish, Glyptothorax telchitta Ham., with notes on its relationship with the mode of life of the fish. Zool. Pole 22(4): 287-295.
- Ojha, P.P. and Kapoor, A.S. (1974). Structure and function of the olfactory organs in the fish Sisor rhabdophorus Ham. Acta. Anat. 87: 124-130.

- Olmsted, J.M.D. (1918). Experiments on the nature of the sense of smell in the common cat fish, Ameiurus nebulosus. Am. J. Physiol. 46: 443-445.
- Ottoson, D. (1963). Some aspects of the function of the olfactory system. Pharmac. Rev. 15: 1-42.
- Parker, G.H. (1910). Olfactory reactions in fish. J. Exp. Zool. 8: 535-542.
- Parker, G.H. (1911). The olfactory reactions of the common Killfish, Fundulus heteroclitus. J. Exp. Zool. 10: 1-5.
- Parker, G.H. (1912). The reactions of smell, taste and the common chemical sense in vertebrates. Proc. Acad. Natl. Sci. Philadelphia 15: 221-234.
- Parker, G.H. (1922). Smell, taste and allied senses in the vertebrates Monogr. Exp. Biol. Lippincott, Philadelphia
- Parker, T.J. and Haswell, W.A. (1951). A Text book of Zoology. (6th edition), Mac Millan and Co., Ltd., London.
- Pfeiffer, W. (1962). The fright reaction of fish. Biol. Rev. Cambridge Phil. Soc. 37: 495-511.
- Pfeiffer, W. (1963). The morphology of olfactory organ of Pacific Salmon (Oncorhynchus): Can. J. Zool. 41: 1233-1236.
- Pfeiffer, W. (1964). The morphology of the olfactory organ of Haplopagrus quentheri Gill, 1862. Can. J. Zool. 42: 235-237.
- \*Pfeiffer, W. (1968). Das Geruchsorgan der Polypteridae (Pisces: Brachiopterygii). Z. Morphol. Oekol. Tiere 63: 75-110.
- \* Pfeiffer, W. (1969). Der Geruchssinn der Polypteridae (Pisces: Brachiopterygii). Z. Vergleich. Physiol. 63: 151-164.
- \* Pipping, M. (1926). Der Geruchssinn der Fische mit besonderer Berücksichtigung seiner Bedeutung für das aufsuchen des futters. Soc. Sci. Comment. Biol. 2:4.
- \* Popova, N.I. (1966). Sravnitel'naya gistokhimicheskaya kharakteristika mukopolisakharidov obonyatel'noi vystilki nekotorykh nozvonochynkh (A comparative histochemical characterization of the flowery polysaccharides of the olfactory lining in some

- vertebrates). Izv. Sib. Otdel. Akad. Nauk, SSSR, Ser. Biol., No. 12, pt. 3 (RZ Biol., 1967, 67 I 653).
- Porter, K.R. and Bonneville, M.A. (1964). An introduction to the fine structure of cells and tissues. Lea and Febinger, Philadelphia.
- Rahmani, A.R. and Khan, S.M. (1977). Functional morphology of the olfactory organs of Anabas testudineus (Bloch). J. Zool. Res. 1: 53-60.
- Rahmani, A.R. (1979). Studies on the anatomy of the olfactory organs of certain teleosts. Ph.D. Thesis, Aligarh Muslim University, Aligarh, India.
- Rahmani, A.R. and Khan, S.M. (1980). Histology of the olfactory epithelium and the accessory nasal sacs of an anabantoid fish, Anabas testudineus (Bloch). Arch. Biol. (Bruxelles), 91: 397-411.
- Rahmani, A.R. and Khan, S.M. (1981). The olfactory organ in a few Indian teleosts. Curr. Sci. 50(7): 329-331.
- Rizvi, N. and Khan, S.M. (1980). Architectonic pattern of olfactory flap of Tetradon patoca. Jour. Ichthyol. 1: 5-9.
- Rizvi, N., Sharma, V.I. and Rizvi, A.W. (1984). The anatomy of the olfactory organs in the fresh water fish Mystus vittatus. Intl. J. Ichthyol. (Proc. IV, AISI), 5: 43-48.
- Rosen, M.W. and Cornford, N.E. (1971). Fluid frictions of fish slines. Nature, 234: 49-51.
- Schaeffer, J.P. (1932). The mucous membrane of the nasal cavity and the paranasal sinuses. In: Special Cytology, Volume 1, Cowdry Editor, Hoeber, New York.
- Schnitzlein, H.N. (1964). Correlation of habit and structure of the fish brain. Amer. Zool. 4: 21-32.
- Schnitzlein, H.N. (1977). The Telencephala of division I of the Teleost Fishes. J. Hirnforach. 18: 157-178.
- \*Schulte, E. (1972). Untersuchungen an der Regio olfactoria des Alas, Anguilla anguilla L. I. Feinstruktur der Riechepithels. Z. Zellforsch. Mikroskop. Anat. 125: 210-228.
- \*Schulte, E. and Hüll, A. (1971). Feinstruktur des Riechepithels Von Calamoichthys calabaricus. J.A. Smith (Pisces, Brachiopterygii). Z. Zellforsch. Mikroskop. Anat. 120: 261-279.

- Scott, W.B. (1887). Notes on the development of Petromyzon.  
J. Morphol. 1: 184-301.
- \* Seiffert, K. (1968). Die Feinstruktur des Riechsaumes.  
Arch. Klin. exp. Ohr. Nas. Kehlk. Heilk. 192:  
182-213.
- Shantha, T.R. and Nakajima, Y. (1970). Histological and  
histochemical studies on the rhesus monkey  
(Macaca mulata) olfactory mucosa. Z. Zellforsch.  
Mikroskop. Anat. 103: 291-319.
- Sharma, V.I. (1981). Studies on the anatomy and histology  
of olfactory organs of certain Teleosts.  
Ph.D. Thesis, Aligarh Muslim University, Aligarh.
- Sheldon, R.E. (1909). The reactions of the dog fish to  
chemical stimuli. J. Comp. Neurol. 19: 273-311.
- Sheldon, R.E. (1911). The sense of smell in selachians.  
J. Exp. Zool. 10: 51-61.
- Sheldon, R.E. (1912). The olfactory tracts and centres in  
teleosts. J. Comp. Neurol. 22: 177-339.
- Shibuya, T. (1960). The electrical responses of the olfactory  
epithelium of some fishes. Jap. J. Physiol. 10:  
317-326.
- Singh, C.P. (1972). A comparative study of the olfactory  
organ of some Indian fresh water teleostean fishes.  
Anat. Anz. 131: 225-233.
- Singh, W. and Singh, H.R. (1986). A SEM study of the olfactory  
rosette of some hillstream fishes Folia.  
Morphol. (Prague) 34(3): 331-335.
- \* Solger, B. (1893). Notiz Über die Nebenhöhle des Geruchsorgans  
Von Gasterosteus aculeatus. L. Z. Wiss. Zool. 57:186.
- Sophie Pereyaslawzeff (1876). Inaug. dissert. Zurich (quoted  
by Burne, 1909).
- Sterba, G. (1962). Freshwater fishes of the world.  
Studio Vista Ltd., London.
- \* Strieck, F. (1924). Untersuchungen Über den Geruchs - Und  
Geschmackssinn der Elritzen. Z. Vergleich.  
Physiol. 2: 122-154.

- \*Teichmann, H. (1954). Vergleichende Untersuchungen an der Nase der Fische. Z. Morphol. Otol. Tiere, 43: 171-212.
- \*Teichmann, H. (1957). Das Reaschvermögen des Hales (Anquilla anquilla L.). Z. Vergl. Physiol. 42: 3.
- \*Teichmann, H. (1959). Über die Leistung des Geruchssinnes beim Aal (Anquilla anquilla L.). Z. Vergl. Physiol. 42: 206-254.
- Theisen, B. (1972). Ultrastructure of the olfactory epithelium in the Australian lungfish Neoceratodus forsteri. Acta. Zool. (Stockholm). 53: 203-218.
- Theisen, B., Breucker, H., Zeiske, E. and Melinkat, R. (1980). Structure and development of the olfactory organ in the garfish, Belone belone (L.) (Teleostei, Atheriniformes). Acta. Zool. (Stockh.) 61: 161-170.
- Thornhill, R.A. (1970). Cell division in the olfactory epithelium of lamprey Lampetra fluviatilis. J. Cell Sci. 2: 591-602.
- Thornhill, R.A. (1972). The ultrastructure of the accessory olfactory organ in the river lamprey (Lampetra fluviatilis). Acta. Zoologica 53: 49-56.
- \*Tret'yakov, D.K. (1939). Obonyatel'ny organ pelamidy (Olfactory organ of bonito). Doklady Akad. Nauk. SSSR, 32: 4.
- Trujillo-Cenoz, O. (1961). Electron microscope observations on chemo and mechano receptor cells of fishes. Z. Zellforsch. Mikroskop. Anat. 54: 654-676.
- \*Uexcüll, J. (1895). Vergleichendsinnenphysiologische Untersuchungen I. Über die Nahrungsaufnahme des Katzenhaies. Z. Biol. 32: 548-566.
- \*Van den Berghe, L. (1929). Observations Sur l'olfaction et Sur le mechanisme des Courants olfactifs chez quelques teleosteens. Bull. Acad. Roy. Belg. Sci. Letter Beaux Arts. 15: 278-305.
- \*Van der Stricht, O. (1909). Le neuro-epithelium olfactif et sa membrane limitante interne. Mem. Acad. Roy. Med. Belg. 20: 1-45.
- Vinnikov, Y.A. (1956). Structure of the organ of smell. Arkh. Anat. Gistol. Embriol. 33: 49-54.

- Vinnikov, Y.A. (1966). Structural and cytochemical organization of receptor cells of the sense organs in the light of their functional evolutions. Fed. Proc. Trans. Suppl. 25, II, T 34-T 42.
- Waghray, Sarala (1986). Olfactory organ and its sexual dimorphism in the electric ray, Narcine timelel. Ind. J. Fish 32(1): 148-151.
- Watling, H. and Hilleman, H.H. (1964). The development of the olfactory apparatus of the grayling (Thymallus arcticus). J. Fish. Res. Bd. Can. 21: 373-396.
- Whelan, James, P., Charles, J. Wysocki, and Lois A. Lampson (1986). Distribution of microglobulin in olfactory epithelium: A proliferating neuroepithelium not protected by a blood tissue barrier. J. Immunol. 137(8): 2567-2571.
- Whitaker, M. (1970). The skin surface of bony fishes. J. Zool. 160: 437-454.
- Wiedersheim (1887). Festschrift V. Kolliker, p. 73 (quoted by Burne, 1909).
- Wilson, J.A.F. and Westermann, R.A. (1967). The fine structure of the olfactory mucosa and nerve in the teleost, Carassius carassius L. Z. Zellforsch Mikroskop. Anat. 83: 196-206.
- \* Wunder, W. (1957). Die Sinnesorgane der Fische. Allgem. Fischereizeitung 82: 171-173.
- Yamamoto, T., Tonosaki, A. and Kurosawa, T. (1965). Electron microscopic studies on the olfactory epithelium in frogs. Acta. Anat. Nippon. 40: 342-353.
- Yamamoto, M. and Ueda, K. (1977). Comparative morphology of fish olfactory epithelium-I. Salmoniformes. Bull. Jap. Soc. Sci. Fish. 43(10): 1163-1174.
- Yamamoto, M. and Ueda, K. (1978a). Comparative morphology of fish olfactory epithelium. II. Clupeiformes. Ibid. 44(8): 855-859.
- Yamamoto, M. and Ueda, K. (1978b). Comparative fish olfactory epithelium. III. Cypriniformes. Ibid. 44(11): 1201-1206.

- Yamamoto, M. and Ueda, K. (1978c). Comparative morphology of fish olfactory epithelium. IV. Anguilliformes and Myctophiformes. Ibid. 44(11): 1207-1212.
- Yamamoto, M. and Ueda, K. (1978d). Comparative morphology of fish olfactory epithelium. V. Gasterosteiformes, Channiformes and Synbranchiformes. Ibid. 44(12): 1309-1314.
- Yamamoto, M. and Ueda, K. (1978e). Comparative morphology of fish olfactory epithelium VI. Siluriformes. Zool. Mag. 87: 254-261.
- Yamamoto, M. and Ueda, K. (1978f). Comparative morphology of fish olfactory epithelium. VII. Gadiformes, Lophiiformes and Gobiesociformes. J. Fac. Sci. Sec. IV. 34(2): 115-125.
- \*Zeiske, E. (1973). Morphologische Untersuchungen am Geruchsorgan Von Zahnkarpfen (Pisces, Cyprinodontidae). Z. Morphol. Oeko. Tiere. 74: 1-16.
- Zeiske, E. (1974). Morphological and morphometric studies on the olfactory organs of oviparous cyprinodont fishes (Pisces). Z. Morphol. Oekol. Tiere. 77: 19-50.
- Zeiske, E., Melinkat, R., Breucker, H. and Kux, J. (1976). Ultrastructure studies on the epithelium of the olfactory organ of cyprinoids (Teleostei: Cyprinodontidae). Cell. Tiss. Res. 172: 245-267.
- Zeiske, E., Breucker, H. and Melinkat, R. (1979). Gross morphology and fine structure of the olfactory organ of rainbow fish (Antheriniformes, Melenotaeniidae). Acta. Zool. (Stockh.) 60:173-186.

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\* References not consulted in original.